HABITAT USE AND SELECTION BY MALE AND FEMALE MOOSE (*ALCES ALCES*) IN A BOREAL LANDSCAPE

by

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Abstract

Moose (*Alces alces*) is a keystone species in boreal landscapes. I quantified seasonal range sizes, movement rates, and use of elevation and land cover for male and female moose in south-central Yukon. I used individual and pooled resource selection functions to define the influence of land cover, topography, predation risk, and harvest vulnerability on habitat selection. Seasonal changes affected use and selection more than gender or reproductive status (females with and without calves). High use and positive selection for shrub-dominated land-cover classes by all individuals in all seasons affirmed forage as a primary force driving seasonal selection patterns. Variation in selection among individuals was highest during the growing seasons and least during late winter, when options were constrained by climatic factors. These findings from telemetered moose generally corresponded with models based on local knowledge-based habitat suitability indices and post-rut locations from aerial surveys; and they contribute to land-use planning processes.

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Chapter 1: Introduction

BACKGROUND

Moose (*Alces alces*) are typically the largest mammal found in boreal forests (except where wood bison (*Bison bison athabascae*) occur) and are a keystone species, playing important roles in predator-prey dynamics, nutrient cycling, and forest succession (Molvar *et al.* 1993, Danell *et al.* 1998). They are also an important focal species in many northern communities, offering subsistence, cultural, economic, and recreational values. The widespread range of moose is a reflection of the species' ability to utilize a wide variety of successional stages found throughout the boreal forest. To maximize survival and fitness, moose must access adequate forage and cover, while minimizing predation and/or harvest risk. In the process of habitat selection, an animal must first choose a general place to live (a habitat or habitats) and then make subsequent decisions about how it moves within habitats and responds to environmental factors (Anderson *et al.* 2005). Differences in patterns of habitat use and selection reflect trade-offs that moose of different reproductive classes make spatially and temporally (Lynch and Morgantini 1984, Miller and Litvaitis 1992, Miquelle *et al.* 1992). In addition to the limiting factors of climate, disease, predation and harvest, resource development can substantially impact the quality and quantity of suitable moose habitat. Northern ecosystems are especially vulnerable to development because they are often less productive and take longer to recover from landscape alterations. Consequently, in the north, alteration of wildlife habitats from disturbance may last longer. The need to define patterns of use and selection by moose, particularly in light of potential resource development, will become increasingly important as wildlife managers cope with increasing demands for abundant and economically valuable natural resources found in the north.

Despite having extensive tracts of intact boreal forest, Yukon has relatively low moose densities, low calf recruitment, low hunting pressure, and lightly-exploited predator populations. The Yukon moose population is generally believed to be maintained in a low-density dynamic equilibrium, primarily by wolf (*Canis lupus*) predation ($\bar{x}$ = 158 moose/1,000 km^2, range = 45–417 moose/1,000 km^2; Florkiewicz *et al.* 2008). Recruitment typically ranges from 5–40 yearlings/100 cows (Gasaway *et al.* 1992). In addition to wolves, grizzly bears (*Ursus arctos*) and black bears (*Ursus americanus*) are also primary predators of moose in Yukon. Low fur prices and limited use of traplines have resulted in healthy wolf populations. Annual allowable harvest rates for moose in Yukon range from 2–5% (Moose Harvest Management Working Group 2012). As in other areas, the spatial extent of moose harvesting in Yukon is generally limited by accessibility—use of roads, waterways or small aircraft. Assuming mineral prices remain economically viable and Yukon's human population continues to grow, the extent of resource development in Yukon will likely increase. Additionally, as demand increases for limited supplies of fossil fuels, northern food prices are expected to rise substantially, which may increase reliance on subsistence harvesting, including moose. Regional land-use planning and environmental assessment processes are currently the main tools used to manage the potential environmental and socio-economic impacts of resource development, and require adequate knowledge of local moose populations.

Few studies have addressed habitat requirements and limiting factors of moose in Yukon. Outside of the early winter, post-rut period (November–early December), relatively little is known about moose distribution, abundance or habitat use. Most studies have focused on predation mortality and control (Larsen *et al.* 1989, Gasaway *et al.* 1992, Boertje *et al.*

1995, Hayes *et al.* 2000a, b). The studies related to habitat use or distribution occurred in southwest (Keith 1995) and northern Yukon (Mauer 1998, Wolfe *et al.* 2011) and only one published study examined effects of disturbance on Yukon moose (logging in southeast Yukon; Florkiewicz and Henry1994). Maintenance of Yukon moose populations, in the face of a changing landscape, will require knowledge of local use and selection patterns, taking into consideration factors such as reproductive status, predation risk, and harvest vulnerability at appropriate spatial and temporal scales.

The South Canol area in south-central Yukon presently has few roads or industrial developments; however, its relatively close proximity to the large community of Whitehorse (population of 23,276) and substantial mineral potential make it a popular hunting area and a likely target for future resource development. Moose density in the area is relatively high (241 moose/1,000 km^2) compared to most of Yukon, and populations are thought to be stable or slowly decreasing (Florkiewicz *et al.* 2008). Local communities (i.e., Teslin and Whitehorse) have expressed a strong interest in the maintenance or enhancement of moose population numbers, regardless of future development. The South Canol area provided an opportunity to obtain baseline information on seasonal habitat use and selection by moose. Detailed information on use and selection and an understanding of the mechanisms driving that selection are needed for effective land-use planning and moose management in south-central Yukon, particularly in light of potential future resource development.

GOALS AND OBJECTIVES

I structured my thesis around 4 goals and related objectives:

Goal 1: Identify attributes that best explain patterns of habitat use and selection by moose in south-central Yukon for subsequent use in land-use planning and impact assessment.

Objective 1a: Determine if male and female moose respond differently to habitat components within their seasonal and annual ranges, as measured by size and land-cover composition of seasonal and annual use areas, and changes in movement rates and use of elevation.

Objective 1b: Compare patterns of seasonal resource selection between male and female moose using resource selection models that include variables based on land cover, topography, and mortality risk.

Objective 1c: Relate habitat use to selection patterns to better understand the response of male and female moose at multiple temporal and spatial scales.

Goal 2: Define the relative effects of predation risk on seasonal habitat use and selection by moose in the South Canol area.

Objective 2a: Create predation risk indices using resource selection models for wolves and grizzly bears from comparable areas in northern British Columbia.

Objective 2b: Use predation risk indices in seasonal resource selection models to determine the degree of selection or avoidance by male and female moose in areas with varying levels of risk.

Goal 3: Combine telemetry data with traditional and local knowledge to define the relative effects of harvest vulnerability on habitat selection by moose.

Objective 3a: Use data from interviews with First Nation and licensed hunters and remote-sensing land-cover data to create an index representing vulnerability of male moose to harvest during rut.

Objective 3b: Use the harvest vulnerability index in resource selection models to quantify the importance of harvest pressure on male moose during rut.

Goal 4: Compare long-term local and traditional knowledge of moose behaviour with shorter-term studies using telemetry data to improve the current understanding of moose behaviour in the South Canol area.

Objective 4a: Compare results from seasonal resource selection models for male and female moose in the South Canol area with seasonal habitat suitability indices (HSIs) created by the Yukon government using local and traditional knowledge from the communities of Whitehorse and Teslin.

Objective 4b: Compare early winter resource selection by moose as defined using short-term GPS telemetry data in this study with results based on multiple years of post-rut aerial survey data provided by the Yukon government.

THESIS ORGANISATION

This thesis is organized into 4 chapters: an introductory Chapter, 2 stand-alone chapters to be submitted for peer-reviewed publication, and a final Chapter that presents the implications of my research relative to management of moose habitat in south-central Yukon. Chapters 2 and 3 are written in the first person plural to acknowledge the contributions of others in publication format.

In Chapter 1 (*Introduction*), I present a northern perspective on the importance of moose to boreal forest ecosystems, a description of the current state of the general moose population in Yukon, Canada and the challenges facing moose management in south-central Yukon.

In Chapter 2 (*A multi-scale approach to quantify variation in home-range size, movement rates, elevation and habitat use of male and female moose (*Alces alces*) in south-central Yukon*), I examine range size, use of land cover and elevation, and movement rates of individual moose relative to reproductive status and seasonality. I examine first-order use by comparing the land-cover composition of 5 seasonal ranges with the annual range of individual moose. For male and female (with and without a calf) moose, I compare land-cover composition of annual and seasonal ranges, and average seasonal and monthly range size, movement rates, and use of elevation.

In Chapter 3 (*Comparing pooled and individual seasonal resource selection models of male and female moose in a multi-predator boreal ecosystem*), I develop seasonal resource selection models for individual moose. Covariates include land-cover class, elevation, aspect, predation risk (from grizzly bears and wolves), and harvest vulnerability (males only). I also create pooled models (pooled across individuals) to compare differences in seasonal selection by male and female moose. I examine the utility of creating pooled models for moose, a non-herding ungulate demonstrating high variability among individuals.

In conclusion, in Chapter 4 (*Implications of GPS telemetry-based research to moose management in south-central Yukon*) I summarize the study findings by comparing patterns in selection or avoidance (Chapter 3) with habitat use information (Chapter 2). I also compare the resource selection models with: 1) results from a habitat suitability index (HSI) based on local knowledge that was recently conducted in part of the same area; and 2) a resource selection function (RSF) created for early winter based on several years of post-rut aerial moose surveys. I provide management recommendations regarding the utility of GPS telemetry-based research and its value relative to future development in the South Canol area of south-central Yukon.

Chapter 2: A multi-scale approach to quantify variation in home-range size, movement rates, and use of elevation and land-cover by male and female moose (*Alces alces*) in south-central Yukon.

ABSTRACT

Moose (*Alces alces*), as a focal species in many northern communities, are increasingly subjected to anthropogenic activities on boreal landscapes. We studied range use by moose (males and females with and without calves) to enable more effective land-use planning in south-central Yukon. We detected seasonal differences in range sizes, movement rates, and use of elevation and land cover by global positioning system (GPS)-collared individuals; but we were unable to identify gender or reproductive (i.e., calf presence) differences. During winter, moose in the South Canol area generally used smaller ranges at lower elevations and moved less within them, presumably limited by snow depths. They used shrub-dominated land cover most in early and late winter, reflecting the role of shrubs as important winter forage. Moose moved up in elevation throughout summer, reaching maximum elevations during rut and early winter. With greater mobility during summer, they used a wider variety of land-cover classes to meet nutritional requirements. Differences between males and females may be more discrete at the finer scale of microsite characteristics. Examining moose behaviour at a finer scale would be informative, but is likely not essential to manage moose, given a highly mobile species and the relatively coarse scale of land-use planning.

INTRODUCTION

Characteristics of home range can offer insight into the strategies that individuals and populations use to maximize survival and reproduction over time. A home range, as the area an animal uses during a specified period of time (Burt 1943), must support growth and reproduction while minimizing exposure to mortality risk for the animal to survive. It must contain the resources the individual requires, including food, cover, and opportunities to reproduce. Even within a species, these needs can vary greatly amongst individuals and over time. Age and sex affect forage and reproductive requirements (Cederlund and Sand 1994); changing environmental conditions affect distribution, quantity, quality and accessibility of forage and cover over the landscape (Telfer 1970, Van Ballenberghe and Peek 1971, Coady 1974). Resources are rarely distributed evenly over time or space, so animals move to access these resources as availability changes. Thus, movement rates affect both range size and intensity of use (Dussault *et al.* 2005a). Home ranges are dynamic and reflect the complex interaction of factors influencing survival.

The widespread geographic range of moose reflects the ability of this species to use a variety of successional stages found throughout the world's boreal forests. With their large body size, moose are relatively well-adapted to the deep snow, cold temperatures and predators found in northern boreal habitats. They frequent a wide variety of stand-cover types and age classes that provide early seral areas for food and mature coniferous cover (Telfer 1984). Conifer species are used primarily as cover to moderate extremes of heat, cold, wind and deep snow, and as security from predators (Timmermann and McNicol 1988, Balsom *et al.* 1996, Mysterud and Ostbye 1999). Use of shrub-dominated areas by moose often corresponds with foraging activity because shrub species make up the majority (>60%) of moose diets throughout the year (Renecker and Schwartz 2007). Mixed-wood areas, interspersed with both conifers and deciduous trees and shrubs, provide a mix of forage and cover, potentially important to both sexes at times of the year when mobility may be limited. Riparian areas also provide a variety of species used for cover and forage. Although alpine areas are generally not considered suitable for moose, riparian zones at high elevations often contain highly-selected *Salix* species, in contrast to drier sites dominated by less-palatable species such as *Betula*. The proximity to a water source can affect movements and range use by moose. In spring, it influences selection of birthing sites (Poole *et al.* 2007). During summer, the aquatic plants associated with wetlands and litoral zones may be important sources of sodium and other limiting nutrients, and may drive foraging strategies in some areas (Belovsky 1981, Belovsky and Jordan 1981, Fraser *et al.* 1982). Streams and lakes function as important travel corridors and escape habitat. Female moose that give birth on islands protect calves from predators on the mainland (Edwards 1983). In winter, frozen waterways function as movement corridors for moose and the wolves that pursue them (Kunkel and Pletcher 2000).

As with other ungulates, foraging behaviour of moose is influenced by differences in forage quality, quantity and accessibility (Andersen and Saether 1992). Moose feed on a wide variety of plant species to meet nutritional requirements (Miquelle and Jordan 1979), and require large amounts of forage because of their large body size (Renecker and Hudson 1992, Renecker and Schwartz 2007). Moose with access to high quantities of forage travel less than in areas where forage is more dispersed (Timmermann and McNicol 1988). Forage quality influences daily activity, range use, and foraging patterns (Saether and Andersen 1990). Not surprisingly then, there can be wide variation in home-range sizes among individuals and between seasons (Phillips *et al.* 1973, Addison *et al.* 1980). In addition, periodic disturbances, such as wildfires, often make food and cover spatially and temporally unpredictable (Cederlund and Sand 1994). Body size, age and sex can influence home-range size because of differing nutritional requirements and social activities between sexes and age groups. Movements between seasonal ranges are usually related to reproductive events (e.g., rut, parturition) and climatic changes (e.g., snow depth). Human activities can also influence the quality of environments available to moose, and directly increase mortality risk. Increased access can increase mortality from vehicle collisions (McLellan and Shackleton 1988, Forman and Alexander 1998, Trombulak and Frissell 2000) and hunting pressure (Courtois and Beaumont 1999, James and Stuart-Smith 2000, Crichton *et al.* 2004). Anthropogenic influences are likely to become more prominent as human density increases and the spatial extent of resource extraction and recreational activities expands.

Moose are found throughout Yukon, where 2 subspecies (*A. a. agigas, A. a. andersoni*) are believed to overlap (Bubenik 2007). Although there has been considerable study of range use by moose in other areas of Canada and Alaska (Dussault *et al.* 2001, Dussault *et al.* 2005a, b, Maier *et al.* 2005, Gillingham and Parker 2009a, Mabille *et al.* 2012), few studies have investigated habitat requirements and limiting factors of moose in Yukon (e.g., Mauer 1998, Hayes *et al.* 2000a, b). Low productivity, low population density, and a much smaller human population make comparisons with some Alaskan and other Canadian studies difficult. Little is known about habitat use and distribution of Yukon moose outside the early winter, post-rut period (November–early December), and no rigorous studies to differentiate between males and females have been done. South-central Yukon, currently with limited access and few industrial activities, has considerable potential for resource extraction, as well as a large population centre located relatively close by, both of which may result in more disturbance and improved access into prime moose habitat. This area provided the opportunity to study group-specific (i.e., male, females with calves, and females without calves) range use and movements to enable more effective resource management of moose in light of the increased future access of development into moose habitats.

We used global positioning systems (GPS) and geographic information systems (GIS) to examine the effect of seasonal variation and sex (including the effect of calf presence on females) on home-range size, movement rates and elevation use by adult moose in the South Canol area of south-central Yukon. In addition, we analyzed land-cover composition of ranges at seasonal, annual and landscape scales to see how use changed over time and space. We predicted that seasonal ranges would be largest in summer when movement was least restricted. We expected that seasonal ranges and movement rates of female moose with calves would be smallest during the calving season when newborn calves have limited mobility and therefore are at greatest risk of predation. Females without calves and male moose were expected to have the smallest ranges and movement rates during late winter, when snow was presumably deepest and body condition was lowest. As a sexually dimorphic species, the ranges of male and female moose were not expected to overlap outside of the breeding season. Additionally, because of their larger size and higher absolute energetic needs, the annual ranges and movement rates of males were expected to be greater than those of females. We also expected female moose to use more cover in all seasons to reduce exposure of calves to predation risk.

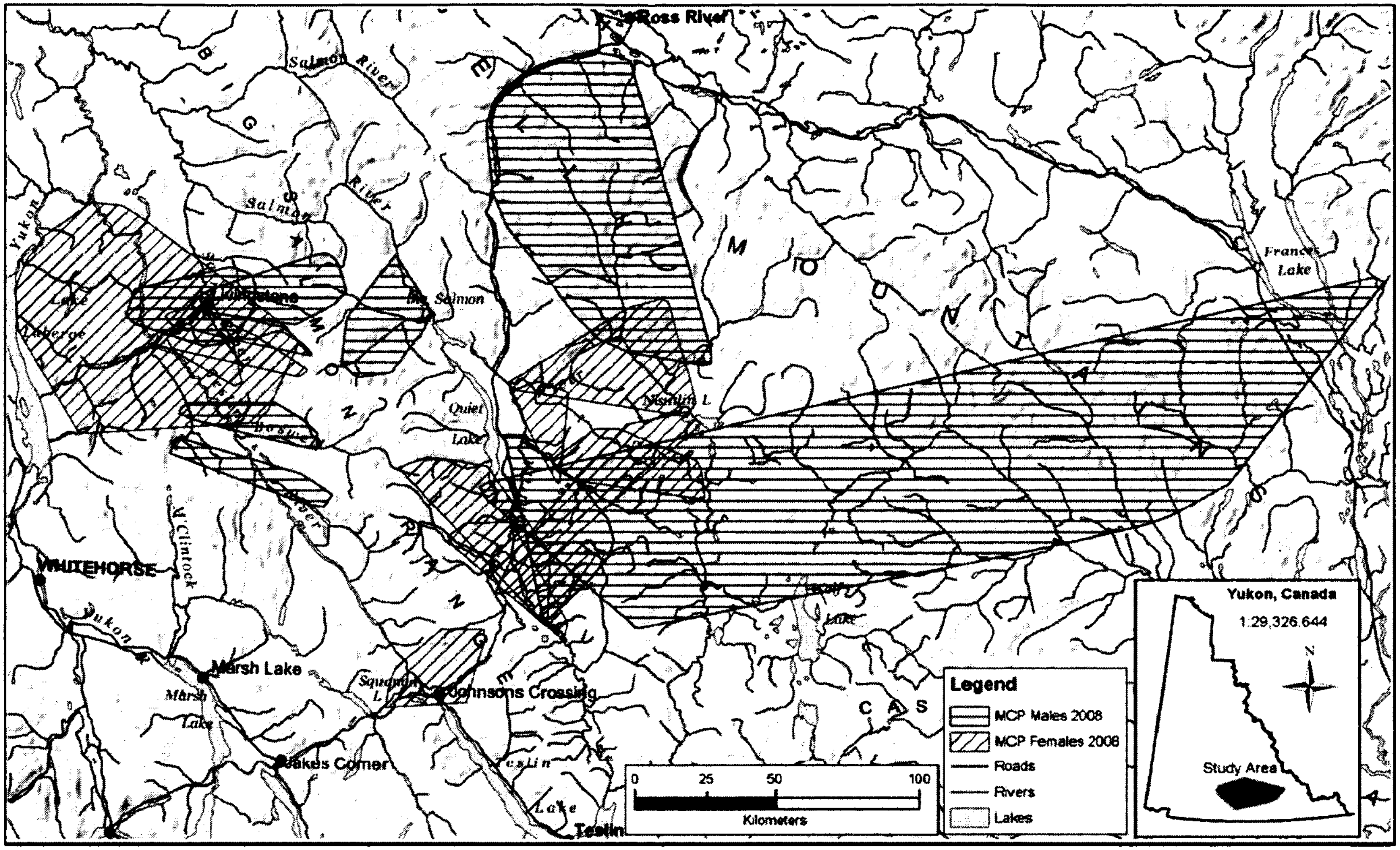
METHODS

Study Area

The South Canol study area in south-central Yukon was 130 km east of Whitehorse and 52 km west of Teslin between 60.4743 and 61.9082°N latitude, and 128.9699 and

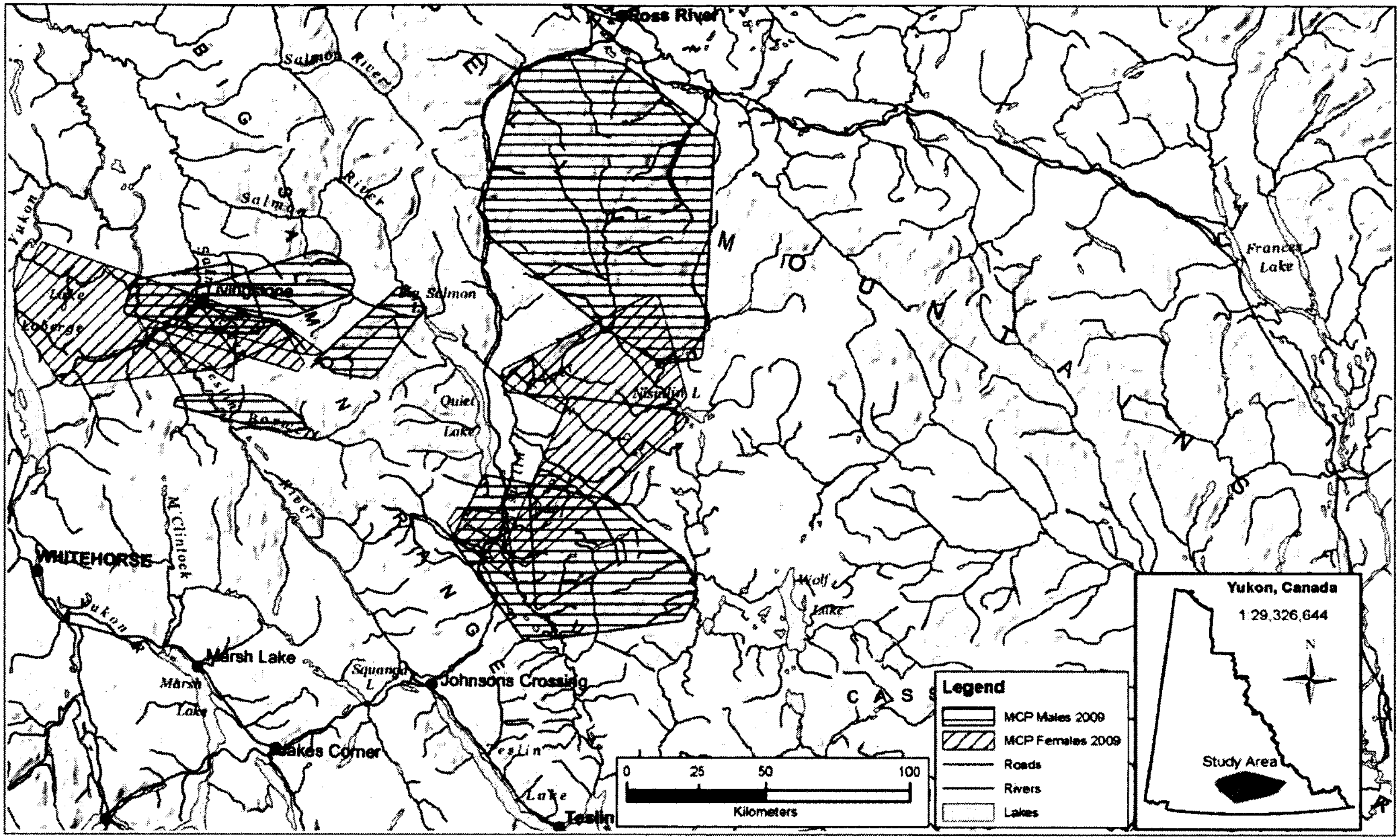
135.2570°W longitude. Covering almost 35,000 km^2, it extended north from Johnson's Crossing, east to Lake Laberge, west of Frances Lake, and south of the community of Ross River (Fig. 2.1). It fell primarily within the traditional territory of the Teslin Tlingit First Nation and also included portions of the Ta'an Kwäch'an, Kwanlin Dun and Kaska traditional territories. The South Canol area was in the Boreal Cordillera Ecozone and included the Pelly Mountains Ecoregion with small portions of the Southern Lakes Ecoregion. The Pelly Mountain Ecoregion is a rolling plateau topped by numerous mountain peaks and dissected by small rivers. The Southern Lakes Ecoregion is characterized by dissected plateaus, rolling hills, and broad valleys occupied by lakes and rivers (Yukon Ecoregions Working Group 2004). The entire area was within the sporadic discontinuous permafrost zone. Shrub and dwarf shrub tundra vegetation occurred above 1,350 m above sea level (a.s.l.); coniferous and mixed forests occurred below 1,350 m a.s.l.

A 2007 population survey of moose reported the average density of moose within a 6,735-km^2 core portion of the study area to be 241 moose/1,000 km^2, which was a higher density than the Yukon average of 158 moose/1,000 km^2. There were approximately 22 calves, 18 yearlings, and 76 males for every 100 adult females (Florkiewicz *et al.* 2008). Grizzly bears (*Ursus arctos)*, black bears (*Ursus americanus*), and wolves (*Canis lupus*) were the main predators in this ecosystem. Wolf density in the study area was estimated to be 8–12 wolves per 1,000 km^2 (Rick Ward, Yukon Department of Environment, *pers. comm.).* The South Canol Road extends from Johnson's Crossing to Ross River and provided access through the eastern portion of the study area. The Pelly Mountains Ecoregion is considered rich in mineral deposits (Yukon Ecoregions Working Group 2004); however, only one hard-rock mineral claim was active (Tintina Mines Ltd.) during the study. An exploration road



2008

Figure 2.1. Study area determined by annual ranges (determined by minimum convex polygon [MCP]) for 8 male and 12 female radio-collared moose in the South Canol study area of south-central Yukon, during 2008 (15 May 2008–14 May 2009) and 2009 (15 May 2009–14 May 2010).



2009
Figure 2.1.continued

was upgraded and extended 76 km from the South Canol Road to Red (Slate) Mountain within the study area. The exploration road was accessible by ATV and 4x4 vehicle in summer and by snowmobile in winter. Several small placer mining operations, some with airstrips and limited roads, were located in the remote northwest portion of the study area.

Animal Captures and Telemetry Data

Twenty-seven moose (9 males, 18 females) were captured between 26 February and 27 March 2008 and fitted with GPS collars (15 collars: Lotek GPS4400M ARG, New Market, ON; 12 collars: Habit Research Inc. (HRI), Victoria, BC). Captures were conducted by Yukon Department of Environment personnel with assistance from the Teslin Tlingit Council. The GPS collars were programmed to acquire locations 6–8 times per day (Lotek: every 4 or 5 hours; HRI: every 3 hours) and periodically uploaded data to the ARGOS satellite (Lotek: every 2 weeks; HRI: every 24 hours). Location data were downloaded from ARGOS once per month. We used Spatial Viewer (M. Gillingham, unpublished Visual Basic program) to examine movement patterns of individual animals and to identify and eliminate errant location points (i.e., those points that were located an improbable distance from previous points) that were likely the result of GPS errors. Location points recorded within 24 hours of capture were not used in analysis. Aerial flights to assess calf status of females occurred 3 times per year (mid-June, October/November and March) in 2008, 2009 and 2010.

Annual and Seasonal Ranges, Movement Rates and Elevation Use

We defined 5 seasons for moose based on life history and biological criteria: Calving, Summer, Rut, Early Winter and Late Winter (Table 2.1). These dates corresponded well with the timing of seasons in other moose studies in Yukon, Alaska, and British Columbia (Larson

Table 2.1. Five seasons defined for moose in the South Canol study area, Yukon.

Season	**Dates**
Late Winter	1 March–14 May
Calving	15 May–30 June
Summer	1 July–14 August
Rut	15 August–31 October
Early Winter	1 November–28 February

et al. 1989, Miquelle *et al.* 1992, Gillingham and Parker 2009a, b). We considered 4 groups of individual moose based on sex and reproductive status (i.e., male, female, female without calf, female with calf). Calf status of females was based on aerial surveys. Only females of known calf status were used in analysis. For example, if a moose had a calf in June and then again in November (i.e., Calving and Early Winter), we also assumed the calf was present during Summer and Rut. If she was alone in November, however, then she was classified as having an unknown calf status during Summer and Rut, and with no calf during Early Winter. For all individual moose, we set 100 locations as a minimum for individual moose to be included in calculations of range size, movement rate, and elevation use in each season (or month).

We estimated annual and seasonal range size (km^2) for each animal from GPS locations using the 100% minimum convex polygon (MCP) method (Jennrich and Turner 1969), with Hawth's Analysis Tools in ArcMap (ESRI 2006). Only complete years (2008: 15 May 2008–14 May 2009; 2009: 15 May 2009–14 May 2010) were used to calculate annual home-range sizes. If an individual had 2 complete years available, we calculated the average size of both years. We identified core areas within each annual and seasonal range using a 95% fixed kernel utilization distribution (Worton 1989). Average seasonal MCP and kernel home-range sizes were determined for each of the 4 moose groups.

We identified available points for each use location by selecting 5 random points from within a buffer surrounding each location point. The radius of the buffer was determined from the 95th percentile movement distance of each individual in each season (Arthur *et al.* 1996). This buffer represents the maximum distance that an animal would likely travel, excluding rare excursions, between consecutive GPS locations, and was used to not under-represent availability if an animal chose not to move very far between GPS fixes. We also calculated a movement buffer around the used and available points of all moose based on the average movement rate of each group. The buffer edge was used to delineate a landscape MCP which represented the area that was available to all moose in this study (i.e., first-order selection based on landscape features; Johnson 1980).

We examined movement by calculating distance moved between consecutive fixes and dividing this by the fix interval to produce a movement rate (m/h). For each location, we extracted elevation from a digital elevation model (DEM; ArcMap 9.3, ESRI, Redlands, CA). We calculated average seasonal and monthly movement rates and elevations used for each individual moose and for each group. Monthly values were used to more precisely define when animals changed movements or elevations. For females with the same calf status in both years, all GPS locations were used to determine the average for each season/month (i.e., not the average of averages); otherwise separate estimates were determined for each year where appropriate.

We used repeated measures 2-way analysis of variance (ANOVA) to investigate the influence of sex and season (or month) on annual and seasonal range size, movement rates, and elevation use. To explore the effect of calf presence on range size, movement rates and elevation use of female moose, we calculated 1-way ANOVAs for each season (calf versus no calf). After transforming the data (MCP: inverse; kernel: inverse square root), we also calculated 1-way ANOVAs to assess the effect of gender on average annual MCP and kernel range sizes.

Land-cover Composition

We developed a land-cover classification using Earth Observation for Sustainable Development of Forests (EOSD) land-cover information, a digital elevation model (DEM), and National Topographic Data Base (NTDB) hydrology information. EOSD (circa 2002) is interpreted from Landsat-7 imagery with 25-m resolution and is used to classify land-surface elements (e.g., vegetation, water, rock) (Wulder *et al.* 2003) (Appendix A). Using remote-sensing software (Geomatica 10.3, PCI Geomatics Enterprises Inc., Richmond Hill, ON), we grouped 26 EOSD cover classes with the above-mentioned data sources to produce 8 land-cover classes relevant to moose ecology (Table 2.2). Classes were combined based on similarities in vegetation and elevation. Grouping classes also had the added effect of improved accuracy of EOSD data, which approached 75–80% (Marcus Waterreus, Yukon Department of Environment, *pers. comm.*). We clipped the raster land-cover classification to each animal's annual and seasonal MCP range, as well as the landscape MCP (Hawth's Analysis Tools, ESRI 2006). We calculated the percent (%) cover of 8 land-cover classes within each of these ranges (Appendix B). We used contingency tables created for each individual to investigate differences between landscape and annual ranges (Dunnett and Gent 1977). We used repeated measures 2-way ANOVA to investigate the influence of gender and season on use of land-cover classes. It was necessary to transform data in most land-cover classes (i.e., square root: Alpine, Upland Shrub, Mixed Wood, Water; log: Low Shrub; Kruskal-Wallis: Riparian, Low Open). We used 1-way ANOVA's to test the effect of calf presence on land-cover use by female moose during calving. Kruskal-Wallis tests were used when data could not be suitably transformed.

Table 2.2. Description of 8 land-cover classes across the South Canol study area of south-central Yukon.

Land-cover Class	% of Study Area	Description
Conifer	45	Spruce, pine or subalpine fir covering 75% or more of total basal area.
Mixed Wood	6	A mix of conifers or deciduous trees with neither exceeding 75% of total basal area.
Lowland Shrub	11	Areas below 1,300 m a.s.l. with ≥ 20% ground cover of which at least 33% is shrub species. Also includes deciduous trees exceeding 75% of total basal area.
Upland Shrub	12	Areas above 1,300 m a.s.l. with ≥ 20% ground cover of which at least 33% is shrub species. Also includes deciduous trees exceeding 75% of total basal area.
Alpine	14	Areas above 1,300 m a.s.l with ≥ 20% ground cover. Includes snow, ice, exposed land, and areas with no data above 1,300 m a.s.l. Excludes Upland Shrub.
Lowland Open	3	Areas below 1,300 m a.s.l with ≥ 20% ground cover, or exposed land with < 5% vegetation. Excludes Lowland Shrub.
Water	2	Lakes, ponds, reservoirs, rivers, streams, or creeks.
Riparian	7	Areas within 25 m of small (1-line[1]) water courses; areas within 100 m of larger water courses (2-line) and water bodies. Includes wetlands.

[1] 1-line streams are smaller streams indicated on 1:50 000 maps with a single line, whereas 2-line streams are indicated using 2 lines to delineate the shores of large rivers.

RESULTS

Between 1 March 2008 and 14 May 2010, 78,687 valid location points from 24 moose (8 males, 16 females) were recorded. Fifteen collars provided 2 complete years of location data, while 9 other collars transmitted data for at least 1 full season. Three HRI collars transmitted for less than 1 season and the small amount of data collected from those 3 individuals was not used in analyses. Collars on male moose had an average fix rate of 88 ± 4% ($\bar{x}$ ± SE; range = 64–98% across individuals). Collars on females had an average fix rate of 66 ± 7% (range = 19–95% across individuals). When examined by collar type, Lotek collars averaged 88 ± 3% fix success compared to only 50 ± 7% by HRI collars.

Landscape

The size of the overall study area (i.e., landscape MCP) was 34,953 km^2. Typical of boreal forest systems, nearly half of the study area was dominated by conifers (*Picea glauca, Picea mariana, Abies lasiocarpa*) (Table 2.2). Shrubs covered slightly less than one quarter of the landscape and were equally distributed between high and low elevations. Alpine areas comprised 14% of the area. Riparian areas, defined by their proximity to water (i.e., within 100 m of large rivers and lakes, or within 25 m of smaller streams) were widely dispersed and covered <10% of the landscape. Mixed Wood areas and Water encompassed 6% and 2% of the study area, respectively.

Annual Ranges on the Landscape

Mean annual 100% MCP home ranges of male moose were almost 2.5 times larger ($\bar{x}$ = 1,243 km^2, range = 199–4,968 km^2, n = 8) than those of female moose ($\bar{x}$ = 502 km^2, range = 142–2,025 km^2, n = 12) (Fig. 2.1). Mean annual 95% fixed kernel ranges were much closer in size between the sexes (males: $\bar{x}$ = 115 ± 23 km^2, range = 56–246 km^2, n = 8; females: $\bar{x}$ = 81 ± 10 km^2, range = 37–164 km^2, n = 12). Because of substantive individual variability, however, differences between male and female range sizes were not statistically significant (MCP: $F_{1,18} = 1.05$, $P = 0.32$; kernel: $F_{1,18} = 1.95$, $P = 0.18$).

Proportions of land-cover classes within individual annual ranges differed from what was available on the landscape (all $\chi^2 > 424$, all $P < 0.001$; Appendix C); and thus, home ranges of radio-collared moose were not located randomly on the landscape.

Seasonal Ranges and Movements

Seasonal range sizes, movement rates, and elevations used were highly variable among individual moose. As a result we were not able to detect significant differences among the 4 groups of moose (i.e., males, all females, females with calves, females without calves). In general, though, males used largest areas during Rut and smallest areas in Late Winter (Table 2.3). Females had largest ranges during Early Winter, and smallest kernel ranges during Late Winter. The coefficient of variation (CV) around ranges used by males was greater than that of females. Males moved at highest rates ($\bar{x}$ = 136 ± 9 m/h) during the Rut, whereas highest movement rates of females ($\bar{x}$ = 115 ± 8 m/h) were in Summer. All moose groups had the lowest movement rates in Late Winter (specifically March; Fig. 2.2A, B). Both males and females used the highest elevations during Rut and the lowest elevations during Late Winter (Fig. 2.2C, D).

Seasonal range sizes (MCP: $F_{1,80} = 0.12$, $P = 0.73$; kernel: $F_{1,80} = 2.37$, $P = 0.13$), movement rates (seasonal: $F_{1,80} = 0.05$, $P = 0.83$; monthly: $F_{1,209} = 0.07$, $P = 0.79$), and the elevations used (seasonal: $F_{1,76} = 2.17$, $P = 0.15$; monthly: $F_{1,165} = 1.64$, $P = 0.20$) did not differ between sexes. Kernel range size ($F_{4,80} = 14.64$, $P < 0.01$), movement rates, (season:

Table 2.3. Mean ($\bar{x}$ ± SE) seasonal and annual 100% minimum convex polygon (MCP) and 95% kernel range sizes (km^2) of radio-collared male and female moose, as well as by reproductive status (females with and without calves), in the South Canol study area of south-central Yukon. Mean values were rounded to the nearest km^2. Seasons are defined in Table 2.1.

Season	**Range Estimator**	**Male** $n = 8$	**Females (All[1])**	**Females (No calf[2])**	**Females (Calf[3])**
Late Winter	MCP	84 ± 47	85 ± 32	85 ± 32	74 ± 48
	Kernel	18 ± 3	16 ± 2	16 ± 2	10 ± 5
Calving	MCP	195 ± 53	115 ± 40	140 ± 84	117 ± 29
	Kernel	40 ± 5	21 ± 3	23 ± 6	21 ± 3
Summer	MCP	290 ± 196	72 ± 15	48 ± 17	51 ± 11
	Kernel	38 ± 8	25 ± 3	24 ± 6	30 ± 5
Rut	MCP	385 ± 222	133 ± 31	160 ± 75	170 ± 43
	Kernel	62 ± 9	34 ± 3	37 ± 7	38 ± 4
Early Winter	MCP	147 ± 64	172 ± 34	161 ± 37	197 ± 29
	Kernel	36 ± 6	37 ± 3	36 ± 3	44 ± 7
ANNUAL	MCP	1243 ± 617	502 ± 150		
	Kernel	115 ± 23	81 ± 10		

[1]Late Winter and Early Winter: $n = 17$; Calving: $n = 22$; Summer and Rut: $n = 14$

[2]Late Winter: $n = 14$; Calving and Early Winter: $n = 12$; Summer and Rut: $n = 9$

[3]Late Winter: $n = 3$; Calving: $n = 10$; Summer, Rut and Early Winter: $n = 5$

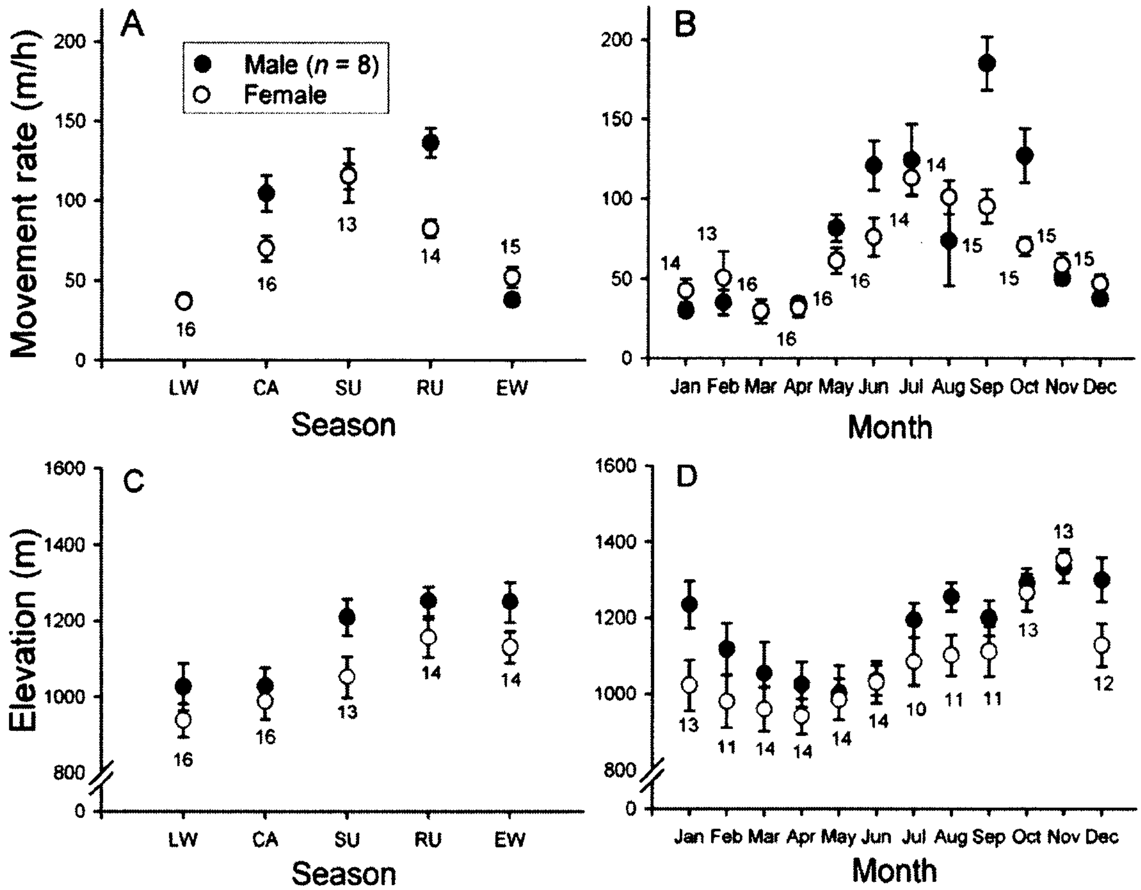


Figure 2.2. Average movement rates (m/h) and use of elevation by season (A, C) and month (B, D) for male and female radio-collared moose in the South Canol study area of south-central Yukon. Numbers shown are sample sizes of female moose. LW = Late Winter, CA = Calving, SU = Summer, RU = Rut, EW = Early Winter.

$F_{4,80} = 42.35$, $P < 0.01$; month: $F_{11,209} = 23.75$, $P < 0.01$) and elevations used (season: $F_{4,76} = 17.88$, $P < 0.01$; month: $F_{11,165} = 12.90$, $P < 0.01$), however, varied with season (and month). Because of high variability among individuals, the seasonal differences in MCP range sizes were not significant ($F_{4,80} = 1.22$, $P = 0.31$). Movement rates differed among seasons, except between Summer and Rut. Calf presence did not significantly affect home-range size, movement rates, or elevation use by females across seasons (Table 2.4, Fig. 2.3), although females with calves tended to move at lower rates during the winter months (Fig. 2.3D).

Percent of land-cover classes used by moose was not affected by sex, with the slight exception of the use of Alpine and Lowland Shrub classes (Table 2.5). Male moose chose annual ranges with a higher proportion of Alpine than in the ranges of females. Season had a significant influence on use of all land-cover classes except the Riparian and Low Open areas. In annual ranges and all seasonal ranges except in Early Winter, moose used Conifer stands more than any other land-cover class (Fig. 2.4). The importance of Upland Shrub (e.g., Early Winter) and Lowland Shrub (e.g., Late Winter) varied with season. During the Calving season, there were no differences in the land-cover classes used by female moose with and without calves (Table 2.6, Fig. 2.5).

DISCUSSION

Moose are known to exhibit high variability in habitat use (Osko *et al.* 2004, Mansson *et al.* 2007, Poole *et al.* 2007, Leblond *et al.* 2010). Striking seasonal changes that occur in boreal systems, as well as cyclical demands of reproduction, strongly influence individual survival. With respect to this variability, we examined range use seasonally and categorized individuals into groups based on gender and reproductive status. Our findings are limited to small sample sizes, potentially confounded by low GPS fix success. Low fix rates can result

Table 2.4. Results of seasonal ANOVAs to determine if calf presence affected range sizes, movement rates, or elevation use of female radio-collared moose in the South Canol study area of south-central Yukon. LW = Late Winter, CA = Calving, SU = Summer, RU = Rut, EW = Early Winter.

	100% MCP				**95% Kernel**				**Movement Rate**				**Elevation**			
Season	***n***	***F***	**df**	***P***	***n***	***F***	**df**	***P***	***n***	***F***	**df**	***P***	***n***	***F***	**df**	***P***
LW	17	0.02	1, 15	0.88	17	0.43	1, 15	0.52	18	0.46	1, 16	0.51	19	0.35	1,17	0.56
CA	22	1.73*	1, 20	0.20	22	0.23[1]	1, 20	0.64	21	1.26	1, 19	0.28	22	1.71	1, 20	0.21
SU	14	0.01	1, 12	0.92	14	0.50	1, 12	0.49	13	0.60	1, 11	0.45	14	0.21	1, 12	0.66
RU	14	0.01	1, 12	0.93	14	0.01	1, 12	0.92	13	0.04	1, 11	0.85	13	0.03	1, 11	0.87
EW	17	0.34	1, 15	0.57	17	1.26	1, 15	0.28	19	0.69	1, 17	0.42	18	0.83	1, 16	0.38

[1] data were ln transformed

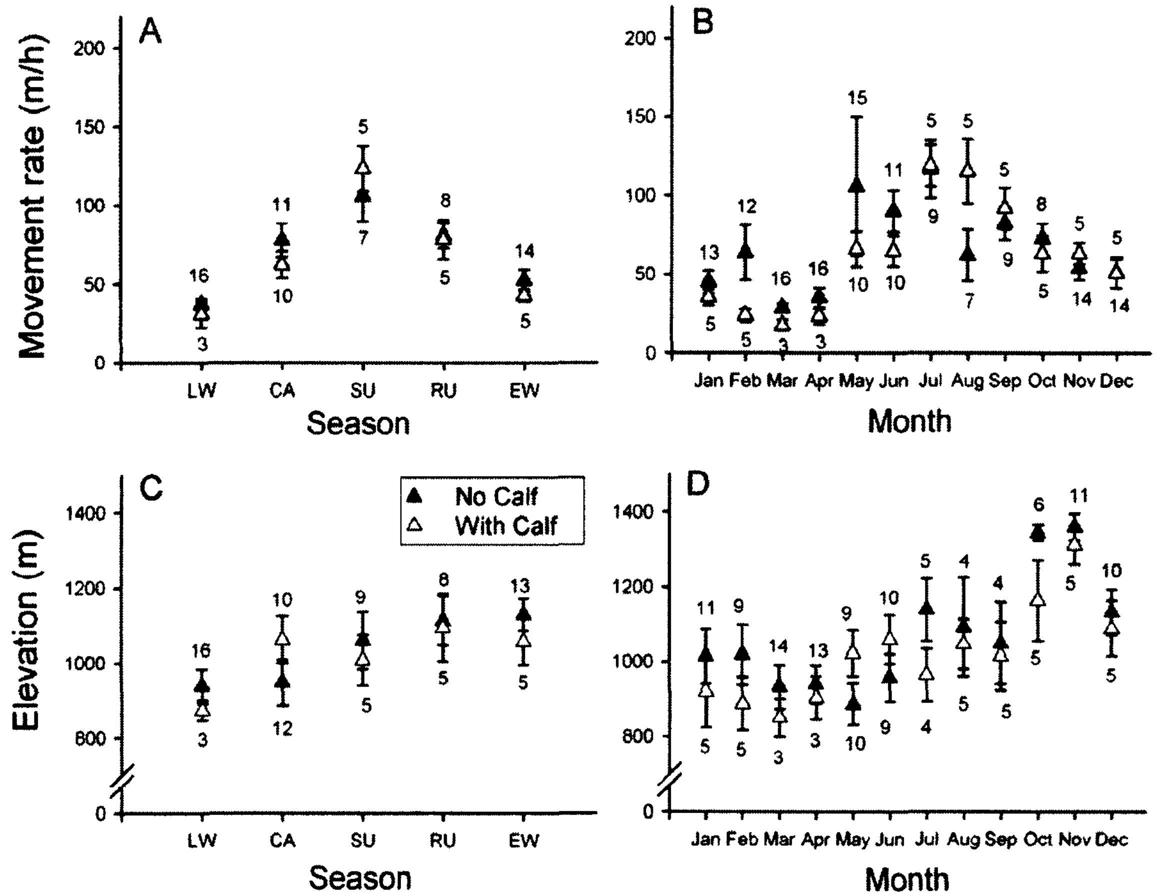


Figure 2.3. Average A) seasonal and B) monthly movement rates (m/h), and C) seasonal and D) monthly elevation use of female radio-collared moose with and without calves in the South Canol study area of south-central Yukon. LW = Late Winter, CA = Calving, SU = Summer, RU = Rut, EW = Early Winter.

Table 2.5. Effects of sex and season on use of 8 land-cover classes by radio-collared moose in the South Canol study area of south-central Yukon as determined by 2-way repeated measures ANOVA. Significant values are indicated in bold.

Land-cover Class		***n***	***F***	**df**	***P***
Conifer	Sex:	23	0.12	1, 107	0.733
	Season:	23	9.18	5, 107	**<0.001**
Lowland Shrub[2]	Sex:	23	0.61	1, 107	**0.048**
	Season:	23	5.25	5, 107	**<0.001**
Upland Shrub[1]	Sex:	12	0.18	1, 54	0.669
	Season:	12	7.65	5, 54	**<0.001**
Alpine[2]	Sex:	11	4.10	1, 49	**0.048**
	Season:	11	11.51	5, 49	**<0.001**
Riparian[3]	Sex:	23	0.01	1, 107	0.922
	Season:	23	1.82	5, 107	0.114
Mixed Wood[2]	Sex:	23	0.33	1, 107	0.569
	Season:	23	2.39	5, 107	**0.043**
Lowland Open[3]	Sex:	20	0.47	1, 94	0.496
	Season:	20	0.61	5, 94	0.689
Water[2]	Sex:	13	0.10	1, 60	0.756
	Season:	13	4.19	5, 60	**0.003**

[1]Log transformation

[2] Square root transformation

[3]Box-cox transformation

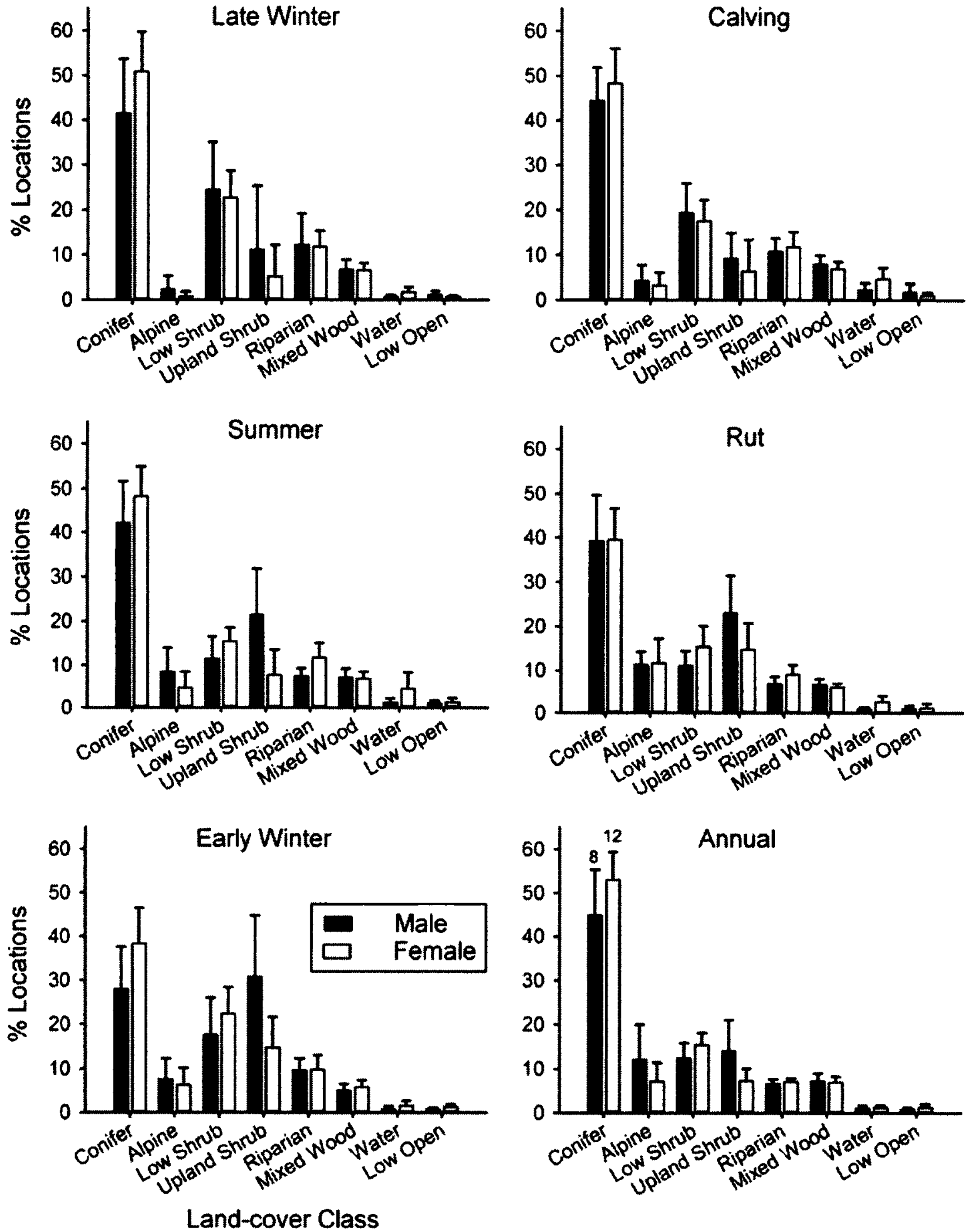


Figure 2.4. Seasonal and annual use (% of locations) of 8 land-cover classes by male and female radio-collared moose in the South Canol study area of south-central Yukon.

Table 2.6. Effect of calf presence on land-cover use by female radio-collared moose during the calving season in the South Canol study area of south-central Yukon, as determined by ANOVA. n = number of individuals.

Land-cover Class	***n***	***F***	**df**	***P***
Conifer	21	1.27	1, 19	0.274
Alpine	7	0.07	1, 5	0.799
Lowland Shrub	21	0.10	1, 19	0.756
Upland Shrub	8	1.82	1, 6	0.226
Mixed Wood	21	1.41	1, 19	0.250
Riparian	21	0.31	1, 19	0.587
Lowland Open	17	0.60	1, 7	0.460
Water	9	0.19	1, 15	0.667

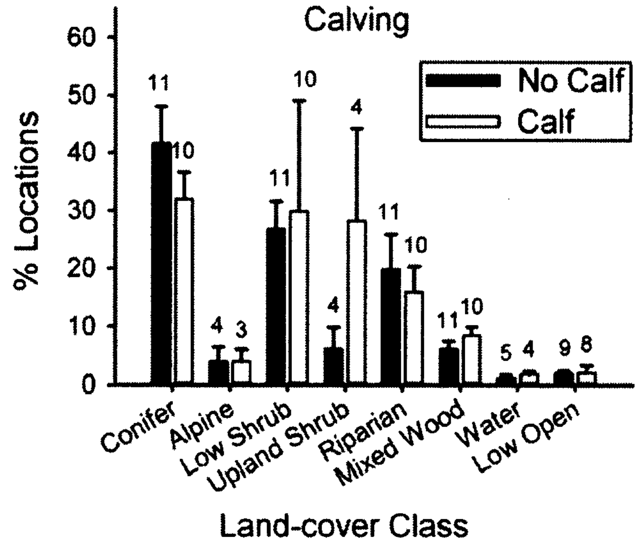


Figure 2.5. Use (% of locations) of 8 land-cover classes by female radio-collared moose with and without calves during the calving season in the South Canol study area of south-central Yukon. Numbers shown are sample sizes.

from location error and missing data can increase type II error. Consequently, low fix-acquisition rates could have introduced GPS-collar bias to locations. Corrections for land-cover or terrain characteristics (Frair *et al.* 2004) or habitat transition probabilities (Nielson *et al.* 2009) were not feasible, nor can such corrections address the geographical space of missing locations (Frair *et al.* 2010). Nonetheless, few studies have radio-collared moose to compare habitat use by gender and reproductive class (e.g., Oehlers 2011). Our findings clarify life-history differences and provide useful insights into management of moose throughout the year.

Ranges Used by Moose

Range sizes, particularly in large sexually dimorphic ungulates, vary with body size, landscape heterogeneity and predictability of resources (Cederlund and Sand 1994, Mysterud *et al.* 2001, van Beest *et al.* 2011). Average annual range sizes of moose in this study were similar to those in northern Canada and Alaska (Doerr 1983, Cederlund and Okarma 1988, Cederlund and Sand 1994, Dussault *et al.* 2005b). In the South Canol area of Yukon, we observed significant differences in size of seasonal ranges. Both MCP and kernel ranges were largest during Rut or Early Winter, when moose likely moved over larger areas to find a mate. Core-area ranges, when defined by 95% kernel utilization, were smallest in Late Winter when snow depth presumably was greatest and body condition poorest. Apparent differences between sexes, however, were not significant. There was no statistical difference between the sizes of average male and female ranges, and calf presence did not affect average range sizes of females. It is possible that sexual differences occurred at a scale finer than used in our study (25-m resolution), in terms of variable use of microsites. Nonetheless, examining seasonal use patterns among males and females (with and without calves) can still be informative. Male moose, perhaps able to travel more freely than females during the growing seasons, had larger home ranges during Calving, Summer and Rut. The coefficient of variation of MCP's was also much greater for males. Larger males, unhindered by the presence of a calf, can be less selective about forage quality (Ruckstuhl 1998, Barboza and Bowyer 2000). Females, which are smaller and consequently less energy-constrained than males during the winter season following the rut, had larger range sizes than males during Early and Late Winter. Unlike males, females face highest energetic demands during Calving and Summer (White and Berger 2001). During Calving, females with calves tended to have smaller ranges than females without calves. The smallest ranges of female moose during the year, however, occurred during Summer. Surprisingly, in this season, females without calves tended to have smaller ranges than those with calves. Perhaps, these females without a calf were less concerned about predation risk and were able to key in on areas with the highest quality forage located at slightly lower elevations and remain there for longer (Timmerman and McNicol 1988). These findings may have also resulted from small sample sizes (Calf: $n = 9$; No calf: $n = 5$).

We used both minimum convex polygons (MCP) and fixed kernel utilization distributions to calculate range sizes. MCPs represent the area where all use locations were recorded, and are more easily compared with other studies. Fixed kernels, on the other hand, highlight core areas, but different contour values and smoothing factors make comparison among studies difficult. Fixed kernel values for seasonal ranges were between 13% and 35% of the size of areas calculated with MCPs. This percentage declined during Summer and Rut for ranges of male moose, but increased for ranges of female moose. This difference between sexes may indicate that males travel over larger areas during Summer and Rut, but favour smaller key areas within that range to meet specific requirements (e.g., mating, feeding). Female moose, in contrast, may target prime habitats initially, and therefore, may not need to be as selective afterward.

Movements of Moose

The timing, speed and extent of seasonal movements by moose observed in our study reflected changing physiological needs (e.g., rut, parturition) and climatic cycles (e.g., green-up, snow conditions). Because of differences in reproductive demands and body size, movement rates may differ among sex and age groups (Testa *et al.* 2000). Coady (1974) reported that winter movement rates were most influenced by the relative ability of individual moose to move in deep snow. Similarly, the movement rates of both sexes of moose in the South Canol area were lowest in Late Winter. This time of year was followed by a rapid increase in movement rates that corresponded with the rapid snowmelt that typically occurs in May. Movement rates generally increased as the growing season progressed, with movement rates peaking in July for females and in September for males. Movement rates then gradually declined as winter progressed. This pattern of rapid movement onto summer ranges and gradual movement onto winter ranges has been observed by others (Coady 1974, vanderWal and Rodgers 2009). A similar pattern of seasonal and monthly movement rates of female moose was observed in northern British Columbia, with comparable climatic conditions and population densities of moose (Gillingham and Parker 2009a).

High individual variation restricted our ability to detect significant differences in movement rates among moose of differing reproductive status (males, females with and without calf at heel). We expected different movement rates based on different energetic demands and the reproductive roles faced by each sex. Although statistically insignificant with our small sample size, the greatest differences between male and female moose in this study were during Calving and Rut, particularly in June, September and October. These are times of the year when the reproductive roles of males and females are most distinct. During the Calving season, prior to giving birth, females may reduce predation risk by making unusual movements (Bowyer *et al.*1999). After parturition, movements of females are limited by newborn calves that have limited mobility in their first month. During Rut, males become preoccupied with finding mates, and/or defending one or more females from rivals. To successfully reproduce, males may travel over long distances or make frequent movements while interacting with mates or rivals (Ballard *et al.* 1991, Leblond *et al.* 2010). Within the female moose group in the South Canol area, movement rates of females with and without calves were more similar than between the sexes. Females without calves moved more in the first half of the year, whereas females with calves had slightly greater movement rates than lone females in the latter months of the year. After the Calving season, when calves have greater mobility, females may move frequently as a way to reduce predation risk (Testa *et al.* 2000). Frequent movements may also be necessary to access larger amounts of high-quality forage that are required to support the energetic demands of feeding and defending a calf. We observed high variation among females without calves during the Calving season, which could have been confounded by misclassification during the aerial calf survival surveys. Females that gave birth but lost their calf by the time the surveys took place in mid-June would have been classified as females without calves. Bowyer *et al.* (1999) found that 78% of calves in Denali National Park, Alaska were killed by predators in the first 20 days of life. Peak calving season in Yukon is during the final week of May (Miquelle *et al.* 1992).

Elevations Used by Moose

Land cover, snow depth, and predation risk may change along altitudinal gradients (Kunkel and Pletcher 2000, Stumph and Wright 2007). In the South Canol area, moose were generally found within a 500-m range in elevation, from valley bottoms up to subalpine areas. Within this 500-m range, elevation acts as a surrogate for snow depth during winter. Moose in other areas have been observed moving down in elevation in response to increasing snow depths (Poole and Stuart-Smith 2006). Indeed, both male and female moose in our study used lower elevations in Late Winter and Calving. The highest elevations were used during Rut and Early Winter, peaking in November. Moose gradually moved down until the end of Late Winter, coinciding with the gradual accumulation of snow over the course of winter in south-central Yukon.

During the Calving season, female moose use a variety of strategies to select birth sites. Bowyer *et al.* (1999) reported that Alaskan moose gave birth at higher elevations, where predators were less abundant. In British Columbia, female moose appeared to associate with 1 of 2 elevational strategies to reduce predation risk: climbers or non-climbers (Poole *et al.* 2007). In our study, there was no statistical evidence for differential elevation use between female and male moose, nor among females with and without calves. We expected elevation use by both sexes to be most similar during Rut, and we observed the least amount of variation in elevation use in October and November. Male and female moose also used very similar elevations during the Calving season, particularly in June, probably in response to initial vegetation green-up. As Summer progresses, so too does the elevational gradient of green-up (Hebblewhite *et al.* 2008). Moose in the South Canol area moved up in elevation during Summer, and again in Rut. The high variation among individual males and females during Summer and after the post-rut period may reflect the variety of strategies that individuals use to maximize energy intake while managing predation risk. Similar seasonal patterns were observed in northern British Columbia (Gillingham and Parker 2009a).

Land-cover Classes Used by Moose

Moose modify their foraging behavior in response to seasonal changes (Saether and Andersen 1990). We observed significant seasonal differences in use of 6 of the 8 land-cover classes in the South Canol area. In Late Winter, moose were less often in the higher elevation land-cover classes (i.e., Alpine, Upland Shrub) than during Summer, Rut or Early Winter, suggesting again that snow depth is a limiting factor for moose in south-central Yukon. Lowland Shrub was used more often in Late Winter than in other seasons. In addition to having lower snow depths, the Lowland Shrub class also provides an important forage base and, therefore, may play a key role in winter survival. During the Calving season, moose also used less Alpine and Upland Shrub than at other times of the year. As such, they remained in areas with higher availability of forage in spring to recover from energetic losses of the previous winter. In spring, we also expected female moose to minimize predation risk to newborn calves by using more cover during the Calving season. Females with calves appeared to use both Upland and Lowland Shrub, which provided forage and reduced predation risk. During Summer, moose continued to use Conifer cover at levels similar to Calving, which in addition to reducing exposure of young calves to predation risk, may be important in moderating extremes of heat. Moose were more likely to encounter Alpine areas as they moved up in elevation over the growing season. Highest nutritional demands occur during lactation, rearing of young, and fat storage (Belovsky and Jordan 1978). Moose consume 3–4 times more food in summer than winter (Renecker and Hudson 1985).

Therefore, we assumed that moose would use shrub-dominated land-cover classes more often during the growing season. Surprisingly, moose in our study used shrub classes proportionally less than during Early or Late Winter. This observation highlights both the ability of moose to use a wide variety of stand cover types and age classes to meet their nutritional requirements in Summer when food is plentiful, as well as the importance of accessible shrub-dominated land-cover during winter when snow depths may be limiting. In Early Winter, moose maximized their use of Upland Shrub while minimizing Conifer use. Both of these patterns, as well as the corresponding use of higher elevations, support our contention that moose generally move up during Rut and stay up until snow depth forces them down later in the winter. Local knowledge also contends that after Rut, moose typically remain in small groups in subalpine areas until the snow pack becomes too deep. It is unclear, however, why these subalpine areas are selectively used at that time of year.

Use of Riparian areas and Water by moose in the South Canol area remained fairly constant over the year. Widespread distribution of water bodies in the study area reduced the likelihood of water being a limiting factor. During the Calving season, however, the Water land-cover class was used more often than the annual average, suggesting that access to water may be an important influence on habitat use during this season. Local knowledge further suggests that access to water is a primary component of birth-site selection. Female moose have higher water demands during lactation and movements with a newborn calf are restricted in the first few weeks after birth.

Conclusions

In south-central Yukon, moose demonstrated seasonal differences in range sizes, movement rates, and use of elevation and land cover. These differences reflected the responses of individual moose to changing resource availability that is characteristic of northern boreal forests. During winter, moose in the South Canol area generally used smaller areas at lower elevations and moved less within them, presumably limited by snow depths. They used shrub-dominated land cover most in Early and Late Winter, reflecting the role of shrubs as critical winter forage. Both cover and water were found to be important elements of the Calving range. Moose moved up in elevation throughout Summer, reaching maximum elevations during Rut and Early Winter. During Summer, with greater mobility, they were able to use a wider variety of land-cover classes to meet nutritional requirements. Therefore, despite needing larger quantities of forage during Summer to meet requirements and replenish body reserves, moose were actually less reliant on shrub-dominated land cover. Other studies have shown that diets are most diverse in summer (Belovsky 1978, 1981). Summer diets are still comprised mostly of shrubs, but moose can obtain a variety of species from forest understories, riparian and open areas, as well as in shrub-dominant areas. Characteristics of the Rut and Early Winter ranges corresponded with local observations that moose in the South Canol area tend to favour subalpine areas and are able to stay there feeding in extensive Upland Shrub communities until snow becomes deep enough to force them to lower elevations. Overall, the results of our study corroborate well with existing local knowledge of seasonal use by moose in this area (McLeod and Clarke 2011).

We were unable to find evidence for differential use between male and female moose, a sexually dimorphic species known to sexually segregate. Individual variation was high, however, and our study was limited to examining range use at the annual and seasonal scales (based on the 25-m resolution of available spatial data). Sexual differences may be more discrete at the finer scale of microsite characteristics. Examining moose behaviour at a finer scale would be informative, but is likely not essential to manage moose, given a highly mobile species and the relatively coarse scale of land-use planning.

Chapter 3: Comparing pooled and individual seasonal resource selection models of male and female moose (*Alces alces*) in a multi-predator boreal ecosystem

ABSTRACT

Moose in Yukon experience an extreme range of thermal conditions, highly variable snow depths, natural and anthropogenic disturbances, population control by predator populations, and hunting pressure. Our objective was to identify variables that best explained habitat-selection patterns of moose in south-central Yukon for subsequent use in land-use planning and impact assessment. We evaluated selection of land-cover class, elevation, aspect, predation risk, and harvest vulnerability from resource selection functions. We created pooled models for males and females by averaging models for individuals by sex and season. Selection of shrub-dominated land cover highlighted the importance of forage accessibility throughout the year. Selection for elevation, aspect, and cover changed throughout the year, as influenced by climatic conditions. Among individuals and between sexes, selection patterns were most variable during the growing season and least variable during winter. Female moose balanced needs for both cover and forage by selecting mixed cover types during calving and summer. Males minimized harvest vulnerability during rut. Moose in general, in our study area, demonstrated highly variable habitat selection; however, consistent individual responses between sexes supported trends identified by pooled selection coefficients, as well as detected trends among males and females.

INTRODUCTION

Habitat selection is a hierarchical process in which an animal first chooses a general place in which to live (a habitat or habitats) and then makes subsequent decisions about how it moves within the habitats and responds to environmental factors (Anderson *et al.* 2005).

Many factors, even those beyond the extent of the home range, influence how animals respond to their environment (Kie *et al.* 2002, Bowyer and Kie 2006). Effective wildlife management benefits from understanding seasonal selection patterns and how animals respond to key habitat variables resulting in those patterns.

Moose (*Alces alces*) use a wide variety of habitats in various successional stages throughout the boreal forest (Kelsall *et al.* 1977). As with most large herbivores, habitat selection is driven by the need to meet nutritional requirements with adequate forage and cover, and to minimize mortality risk. Moose feed on a wide variety of plant species (Miquelle and Jordan 1979), and require large amounts of forage because of their large body size (Renecker and Hudson 1992, Renecker and Schwartz 2007). They adjust foraging behaviour in response to seasonal changes in forage quality and quantity (Andersen and Saether 1992). Habitat selection by moose is strongly influenced by ambient conditions. Both vegetative cover and topography affect microclimate, snow depth and density, and predation risk (Mysterud and Ostbye 1999). Moose use cover and topography in all seasons to moderate extremes of cold (<-30°C in winter) and heat stress (Renecker and Hudson 1986). They increase use of cover with increasing snow depth, density or crusting (Telfer 1970, Van Ballenberghe and Peek 1971). Deep snow may also impair defence capabilities of moose (Peterson and Allen 1974). Wolves (*Canis lupus*), grizzly bears (*Ursus arctos*) and black bears (*Ursus americanus*) are the primary predators of moose in boreal systems. The vulnerability of moose to predation is influenced by snow depth, as well as age, size and body condition; population densities of both moose and predators; and the availability of alternative prey (Hayes *et al.* 2000a). Anti-predator behaviour varies with the degree of predation risk, group size, experience and gender. Moose behaviour and population dynamics are further affected by moose density, which itself is influenced by hunter density, timing of the hunting season, and accessibility (Baskin *et al.* 2004).

In addition to the effects of seasonal changes in forage, climate, and risk, differences in body size and reproductive roles between male and female moose may also vary habitat selection. Sexual segregation, as the differential use of space by the sexes outside of the breeding season, is widespread in sexually dimorphic ungulates such as moose. Most hypotheses for sexual segregation relate to reproductive strategies, sexual dimorphism, and/or social factors (Main *et al.* 1996). These hypotheses suggest that males should maximize body condition before rut and minimize energy expenditures during winter, even if predation risk increases. Larger rumen size allows them to target large quantities of coarse forage and larger body size puts them at less risk of predation. In contrast, females have a smaller digestive capacity, energetic demands of gestation, parturition and lactation, and potentially greater exposure to predation risk. Females should feed more frequently while targeting areas with higher-quality forage in close proximity to cover (Barboza and Bowyer 2000) to meet minimum resource requirements while maximizing security of calves (Main and Coblentz 1990).

Few studies have addressed habitat requirements and limiting factors of moose in Yukon, where the distribution of moose reaches some of the most northern limits of the species' range. Moose in Yukon experience extreme thermal conditions, highly variable snow depths, natural and anthropogenic disturbances that alter land cover, natural regulation by predator populations, and hunting pressure. Moose also are a focal species of many northern communities for subsistence, cultural, economic and recreational values.

The overall objective of this study was to identify variables that best explained resource selection patterns of moose in south-central Yukon for subsequent use in land-use planning and impact assessment. Prior to our study, relatively little was known about the distribution, abundance or habitat use of Yukon moose outside of the early winter, post-rut period (Larsen *et al.* 1989, Gasaway *et al.* 1992, Florkiewicz and Henry 1994, Boertje *et al.* 1995, Keith 1995, Mauer 1998, Hayes *et al.* 2000a, b). We incorporated topographical attributes, land cover, predation risk from wolves and grizzly bears, and harvest vulnerability into resource selection models. Resource selection functions (RSF) describe the relative selection of attributes used by an animal (Manly *et al.* 2002) and provide a broad-scale perspective of general selection patterns on the landscape (Boyce and McDonald 1999). We hypothesized that moose would optimize survival by selecting land-cover classes that minimize energy losses in winter and that maximize potential forage intake during the growing season. Because of physiological and reproductive differences, however, we expected male and female moose to use different strategies to meet these needs. In addition to metabolic demands, moose also faced exposure to mortality risk from predators and hunters. We expected female moose to reduce exposure to predation risk throughout the year, particularly when calves were young. Male moose were expected to reduce exposure to harvest risk during the hunting season.

METHODS

Study Area

The South Canol study area in south-central Yukon was 130 km east of Whitehorse and 52 km west of Teslin, between 60.4743 and 61.9082°N latitude, and 128.9699 and 135.2570° W longitude. Covering approximately 35,000 km^2, it extended north from

Johnson's Crossing, east to Lake Laberge, west of Frances Lake, and south of the community of Ross River (Fig. 3.1). Climate in the South Canol area was characterised by short cool summers and long cold winters. Mean annual precipitation ranged from 500 to 650 mm. Most precipitation fell as snow in winter. Mean annual temperature was -3°C, with a mean January temperature of -20°C and a mean July temperature of 10°C (Yukon Ecoregions Working Group 2004). Unlike many other areas of the Yukon, the South Canol area has had very few wildfires in the past 60 years (Yukon Department of Energy, Mines and Resources 2004). The area was in the Boreal Cordillera Ecozone and includes the Pelly Mountains Ecoregion with small portions of the Southern Lakes Ecoregion. The Pelly Mountain Ecoregion is a rolling plateau topped by numerous mountain peaks and dissected by small rivers. The Southern Lakes Ecoregion is characterized by dissected plateaus, rolling hills and broad valleys occupied by lakes and rivers (Yukon Ecoregions Working Group 2004). The entire area is within the sporadic discontinuous permafrost zone. Shrub and dwarf shrub tundra vegetation occurred above 1,350 m above sea level (a.s.l.), and coniferous and mixed forests occurred below 1,350 m a.s.l.

The average density of moose within a 6,735-km^2 core portion of the study area in 2007 was 241 moose/1000 km^2, which is a higher density than the Yukon average of 158 moose/1000 km^2 (Florkiewicz *et al.* 2008). There were approximately 22 calves, 18 yearlings, and 76 males for every 100 adult female moose. The area also encompassed the ranges of 5 woodland caribou (*Rangifer tarandus*) herds, including the Wolf Lake, Pelly, Carcross, Atlin, and Laberge herds (Yukon Ecoregions Working Group 2004). Stone's sheep (*Ovis dalli stonei*) used the Big Salmon Range in the northern part of the study area, and

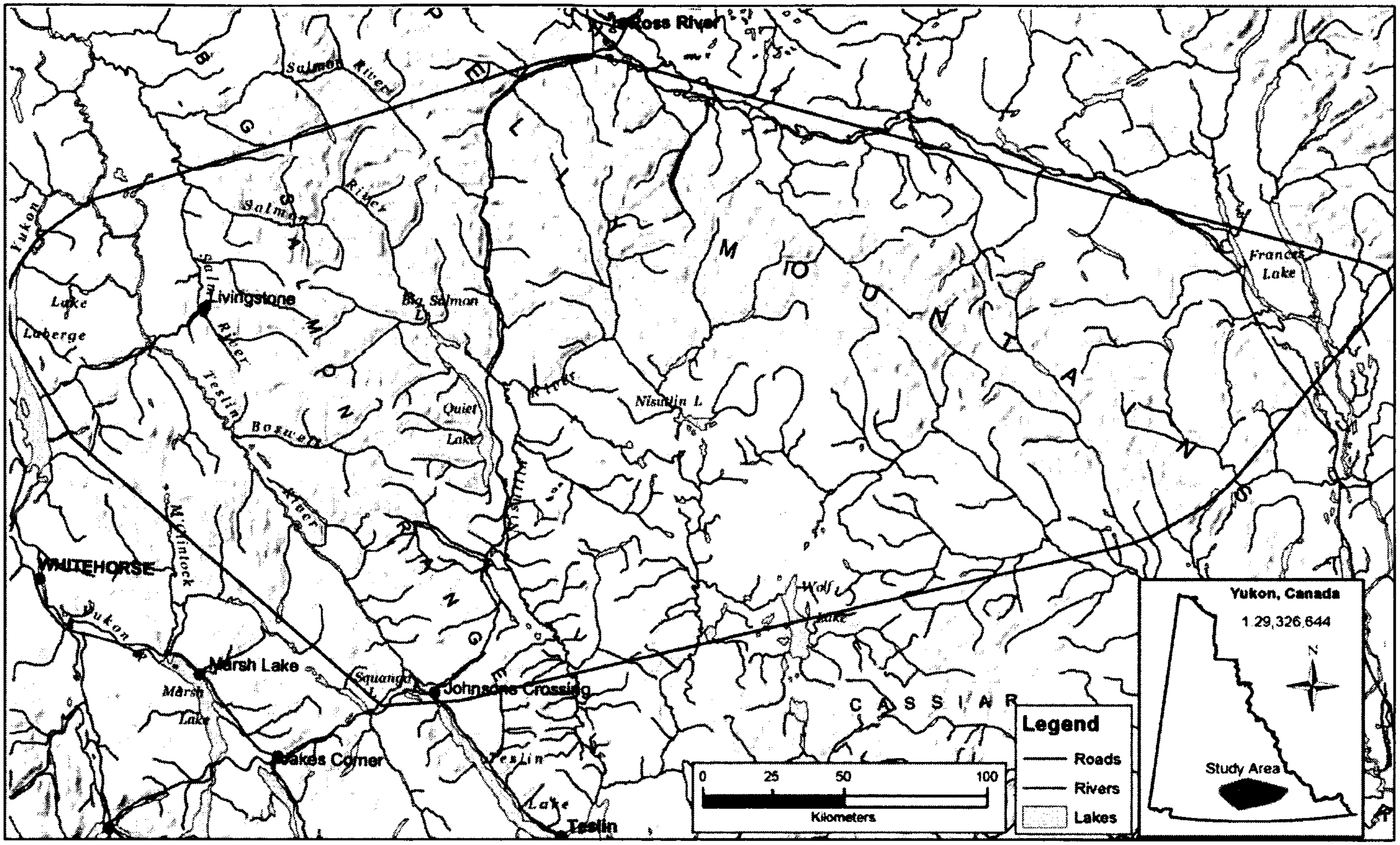


Figure 3.1. South Canol moose study area located in south-central Yukon, Canada.

grizzly bears, black bears and wolves occurred throughout the area. Wolf density was reported to be 8–12 wolves per 1,000 km^2 (R. Ward, Yukon Department of Environment, *pers. comm.*, Baer 2011).

The South Canol area falls mainly within the traditional territory of the Teslin Tlingit First Nation and also includes portions of the Ta'an Kwäch'än, Kwanlin Dun and Kaska traditional territories. Eight Game Management Subzones (GMS), one big-game outfitting concession, and portions of 17 registered trapping concessions were in the study area. Approximately half of the trapping concessions were operated by local First Nations (T. Boyes, Teslin Tlingit Council, *pers. comm.)*. The average annual reported moose harvest (2002–2006) for the area was approximately 1.7 % of the population (Florkiewicz *et al.* 2008). This estimate did not include unreported First Nations harvest, which was estimated to equal the licensed harvest.

Very little development was present in the study area. The South Canol Road, as a seasonal unpaved highway that extends from Johnson's Crossing to Ross River, provided access through the eastern portion of the study area (Fig. 3.1). The Pelly Mountains Ecoregion is considered rich in mineral deposits (Yukon Ecoregions Working Group 2004), but only one hard-rock mineral claim was active during our study (Tintina Mines Ltd.). An exploration road was upgraded in 2008 and extended 76 km from the South Canol Road to Red (Slate) Mountain within the study area. This exploration road was accessible by ATV and 4x4 vehicle in summer and by snowmobile in winter. Several small placer-mining operations, some with airstrips and limited roads, were present in the remote northwest portion of the study area.

Animal Captures and Telemetry Data

Twenty-seven moose (9 males, 18 females) were captured between 26 February and 27 March 2008 and fitted with global positioning satellite (GPS) collars (15 collars: Lotek GPS4400M ARG, New Market, ON; 12 collars: Habit Research Inc., Victoria, BC). The GPS collars were programmed to acquire locations 6–8 times per day (Lotek: every 4 or 5 hours; Habit: every 3 hours) and periodically uploaded data to the ARGOS satellite (Lotek: every 2 weeks; Habit: every 24 hours). Location data were downloaded from ARGOS once per month. We used Spatial Viewer (M. Gillingham, unpublished Visual Basic program) to examine movement patterns of individual animals and to identify and eliminate errant location points (i.e., those points that were an improbable distance from previous points) that were likely the result of GPS errors. Location points recorded within 24 hours of capture were not used in analysis. Aerial flights to assess calf survival occurred during mid-June, October/November, and March of 2008, 2009 and 2010.

We defined 5 seasons based on moose life history and habitat characteristics (Table 3.1). These dates generally corresponded with the timing of seasons in other moose studies in Yukon, Alaska, and British Columbia (Larson *et al.* 1989, Miquelle *et al.* 1992, Gillingham and Parker 2009a, b).

Study Design

We used resource selection functions to assess habitat selection of moose in the South Canol study area. Coefficients were estimated using logistic regression software (STATA 11, StataCorp, College Station, TX) for the parameters of exponential resource selection functions (RSFs) with used and available points for individual animals (Design 3: Thomas and Taylor 1990, 2006). Used points were the GPS fixes from each radio-collared moose.

Table 3.1. Five seasons defined for seasonal habitat selection by moose in the South Canol area, Yukon.

Season	Dates
Late Winter	1 March–14 May
Calving	15 May–30 June
Summer	1 July–14 August
Rut	15 August–31 October
Early Winter	1 November–28 February

Availability was identified by selecting 5 random points from within a buffer surrounding each location point. The radius of each buffer was based on the 95th percentile movement distance of each individual in each season. We assumed the individual could have potentially moved anywhere within this buffer over the period represented by the GPS fix. The randomly-selected available points were inspected for any duplicates (with both location and other random points), which were eliminated. We were not concerned about a slight imbalance in the number of random points because we did not use a matched case design. We then used raster remote-sensing software to query the attributes of each used and available point.

Attributes for Resource Selection

Land-cover Composition

We developed a land-cover classification using Earth Observation for Sustainable Development of Forests (EOSD) land-cover information, a digital elevation model (DEM), and National Topographic Data Base (NTDB) hydrology information (www.geomaticsyukon.ca). EOSD (circa 2002) was interpreted from Landsat-7 imagery with 25-m resolution and was used to classify land-surface elements (e.g., vegetation, water, rock) (Wulder *et al.* 2003, Appendix A). Using remote-sensing software (Geomatica 10.3, PCI Geomatics Enterprises Inc., Richmond Hill, ON), we combined 26 EOSD cover classes with the above-mentioned data sources to produce 8 land-cover classes relevant to moose ecology (Table 3.2). Classes were combined based on similarities in vegetation and elevation. Grouping classes also had the effect of improving the accuracy of EOSD data, which approached 75-80% (M. Waterreus, Yukon Department of Environment, *pers.comm.*).

Table 3.2. Description of 8 land-cover classes used by radio-collared moose in the South Canol study area of south-central Yukon.

Land-cover Class	Description
Conifer	Spruce, pine or subalpine fir covering 75% or more of total basal area.
Mixed Wood	A mix of conifers or deciduous trees with neither exceeding 75% of total basal area.
Lowland Shrub	Areas below 1,300 m a.s.l. with ≥20% ground cover of which at least 33% is shrub species. Also includes deciduous trees exceeding 75% of total basal area.
Upland Shrub	Areas above 1,300 m a.s.l. with ≥20% ground cover of which at least 33% is shrub species. Also includes deciduous trees exceeding 75% of total basal area.
Alpine	Areas above 1,300 m a.s.l with ≥20% ground cover. Includes snow, ice, exposed land, and areas with no data above 1,300 m a.s.l. Excludes Upland Shrub.
Lowland Open	Areas below 1,300 m a.s.l with ≥20% ground cover, or exposed land with < 5% vegetation. Excludes Lowland Shrub.
Water	Lakes, ponds, reservoirs, rivers, streams, or creeks.
Riparian	Areas within 25 m of small (1-line[1]) water courses; areas within 100 m of larger water courses (2-line) and water bodies. Includes wetlands.

[1] 1-line streams are smaller streams indicated on 1:50 000 maps with a single line, whereas 2-line streams are indicated using 2 lines to delineate the shores of large rivers.

Topographic Variables

Elevation and aspect were extracted from a DEM using ArcMap (ArcMap 9.3, ESRI, Redlands, CA). We entered elevation as a quadratic in all selection models to be able to discriminate selection for mid-elevation locations. To reduce the number of categorical variables, we converted aspect into 2 continuous variables: northness and eastness (Gillingham and Parker 2008). Northness (the cosine of aspect) values range from 1.00 to -1.00, indicating north through south aspects. Eastness (the sine of aspect) values range from 1.00 to -1.00, indicating east through west aspects. The values for both northness and eastness must be interpreted together to understand selection for aspect. For example, values near zero for both northness and eastness indicate no selection for aspect, whereas large negative values for both northness and eastness indicate selection for south-west aspects. Slopes of $\leq 1°$ were not assigned an aspect.

Predation Risk

Predation risk to moose was defined using RSFs developed for data from GPS-collared wolves and grizzly bears in the Besa-Prophet area of northern British Columbia (Appendix C). Details of the selection models are in Milakovic (2008) and in Milakovic *et al.* (2011, 2012). These predator-selection models included elevation, slope, aspect, vegetation type, and fragmentation (an index of vegetation diversity). We assumed that risk of predation to moose by wolves and grizzly bears was directly related to selection values for the predators. We generated predation-risk surfaces for moose in the South Canol area as GIS raster layers that defined selection value to wolves or grizzly bears in each season by applying the coefficients from the Besa-Prophet predator-selection models to each 25 x 25-m pixel, based on its topographic and land-cover features. We scaled values from 0 – 1 to standardize selection surfaces and to facilitate comparison between seasons. We created 5 seasonal wolf risk surfaces, and 3 seasonal grizzly bear risk surfaces (with no risk during hibernation seasons).

In addition to predation risk as a variable in resource selection models, we calculated the predation risk that each individual moose was exposed to in each season (based on predation risk values at GPS locations), and averaged the values for males and females. We set a minimum of 100 location points per individual in each season to be included in calculations. We used a repeated measures 2-way analysis of variance (ANOVA) to investigate the influence of gender and season on response to predation risk. To explore the effect of calf presence on predation risk to females, we calculated 1-way ANOVAs for each season (calf versus no calf).

Harvest Vulnerability

Harvest information was collected from First Nations and licensed resident hunters who harvested moose in the study area during the 5 years before moose telemetry locations (i.e., 2004–2008). We collected information about the characteristics of sites where moose were killed. Interviewees were asked to specify on a map where the kill occurred, to comment on proximity to road or water access, and to identify which land-cover class the animal was in, based on examination of several representative photographs of the different land-cover classes (Appendix D).

We developed a raster surface that defined harvest vulnerability to male moose during Rut using the location data collected from hunters, land-cover classes, and NTDB hydrology and road information. This surface was based on a matrix that included each land-cover class, in combination with distance to both roads and large rivers (>500 m or <500 m from roads,

>500 m or <500 m from rivers). The number of moose killed, as recorded in the interviews, was entered into each cell of the matrix. To keep harvest vulnerability as a continuous variable, we converted these values into a proportion of total kills. We then assigned the appropriate proportion to each 25 x 25-m pixel based on land-cover class and distance to access.

We also calculated the harvest vulnerability that each individual was exposed to during Rut, and averaged the values for male and female moose. Only individual moose with a minimum of 100 location points were included in calculations. We used a 1-way ANOVA to investigate the influence of gender on response to harvest vulnerability.

Modeling Procedures

We used the information-theoretic approach to evaluate seasonal resource selection by moose (Burnham and Anderson 2002). First, we developed a set of 10 *a priori*, ecologically plausible models to describe resource selection (Table 3.3). We evaluated the importance of land-cover class, elevation, aspect, predation risk, and harvest vulnerability in the models using selection coefficients (β_i) from logistic regression. A set of 6 models was tested on location data from all moose; we ran 4 additional models for male moose during Rut. We used statistical software for all modeling procedures (STATA 11, StataCorp, College Station, TX). Deviation coding (using DESMAT add-in) was used to avoid complete or near-complete separation in levels of categorical variables (Menard 2002). To avoid issues of separation, we dropped both used and available points in land-cover classes where there were $\leq$4 used or available points. Consequently, very strong avoidance of a particular land-cover class may not always be reflected in the final RSFs. We ranked the model sets using Akaike's Information Criterion (AIC_c) for small sample sizes. Akaike's weights (w_i) indicate

Table 3.3. Candidate resource selection models for moose in the South Canol study area. M = males, F = females, L = land-cover class, E = elevation, A = aspect, P = predation risk, H = harvest vulnerability.

Model	Late Winter		Calving		Summer		Rut		Early Winter	
	M	F	M	F	M	F	M	F	M	F
L	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
E + E2 + A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
P[1]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
L + E + E^2+ A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
L + E + E^2+ A + P[1]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
L + P[1]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
H							✓			
L + H							✓			
L + P + H							✓			
L + E + E^2+ A + P[1]+ H							✓			

[1] Both wolf and grizzly bear predation risk during Calving, Summer and Rut; wolf risk only during Early and Late Winter.

the relative weight of evidence for the top model being the best among the candidate models. We selected a model as the likely top model if $w_i \geq 0.95$. We used k-fold cross-validation averaged across 5 random subsets and an averaged Spearman's rank correlation (r_s) to determine the predictive ability of each top model; values of $r_s > 0.70$ indicated good model performance (Boyce *et al.* 2002). If the top model for each animal had a $w_i < 0.95$, we averaged the selection coefficients (β_i) from the set of top candidate models for which the sum of their respective w_i's was ≥ 0.95 (Burnham and Anderson 2002). When model averaging was required, averaged coefficients from each component model were weighted by their corresponding w_i values; we used a selection coefficient of zero for any parameters not included in an individual's final model to avoid overemphasizing the importance of coefficients that were only in some individual models. Our estimates of pooled variance and standard errors (SE) were based on differences between the coefficient for each model being averaged and the average coefficient across models (weighted by w_i when averaging within competing models for an individual and weighted equally when averaging across individuals; e.g., Murtaugh 2007). Because each individual has a variance associated with its estimate, however, we also included (in an additive manner) the variance of each coefficient in each model in our calculations.

Once we had a single model for each individual, we produced a pooled RSF for males and for females by averaging models across all individuals in that group (using either the top model or an averaged model for each individual as described above) by season. Each model in a sex-season set was equally weighted to avoid over-representation of any individual moose. Models also were developed for females with and without a calf to determine if calf presence affected habitat selection during Calving; a time when newborn calves are most vulnerable.

RESULTS

Over the course of 26 months, 77,309 valid location points from 24 moose were recorded and used in analyses. Fifteen collars provided 2 complete years of location data, while 9 other collars transmitted for at least one full season. Three collars transmitted for less than one season and the small amount of data collected from those 3 individuals was not used in analyses. Hence data were analyzed for 8 males and 16 females.

Seasonal Mortality Risk

Average exposure to wolf risk was lowest during Early Winter for both male and female moose (Fig. 3.2A). It was highest during Rut for females, and during Late Winter for males. Average exposure to grizzly bear risk was lowest during Summer and highest during Rut for both sexes (Fig. 3.2B). Apparent differences between males and females, however, were not significant (wolves: $F_{1, 88} = 0.07$, $P = 0.79$); bears: $F_{1, 44} = 0.26$, $P = 0.61$). Predation risk was a function of season (wolf: $F_{4, 88} = 5.51$, $P < 0.01$; bear: $F_{2, 44} = 12.08$, $P < 0.01$). Wolf risk during Early Winter was lower than during Summer. Calf presence had a significant effect on the wolf risk encountered by females only during Late Winter (Table 3.4), when female moose with calves used areas with lower risk than females without calves (Fig. 3.3A, B). There was no significant difference in exposure to harvest risk during the Rut season between male and female moose (Kruskal-Wallis: $\chi^2 = 0.91$, df = 1, $P = 0.34$).

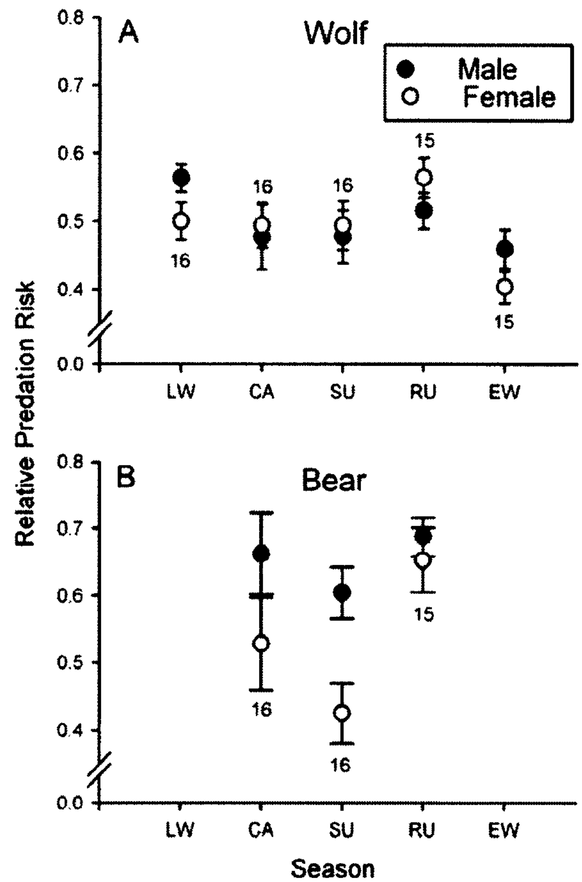


Figure 3.2. Average ($\bar{x}$ ± SE) seasonal predation risk by A) wolves and B) grizzly bears to male and female radio-collared moose in the South Canol area of south-central Yukon. LW = Late Winter, CA = Calving, SU = Summer, RU = Rut, EW = Early Winter. Numbers indicate sample size of females.

Table 3.4. Effect of calf presence on relative risk of wolf and grizzly bear predation within seasonal habitat selection by female radio-collared moose in the South Canol study area of south-central Yukon, as determined by ANOVA. Significant values are in bold.

Season	Wolf Risk				Bear Risk			
	n	*F*	df	*P*	*n*	*F*	df	*P*
Late Winter	19	6.95	1, 17	**0.02**				
Calving	22	0.01	1, 20	0.94	22	3.52	1,20	0.08
Summer	16	0.91	1, 14	0.36	16	0.08	1, 14	0.78
Rut	15	1.28	1, 13	0.28	15	0.99	1, 13	0.34
Early Winter	20	0.33	1,18	0.57				

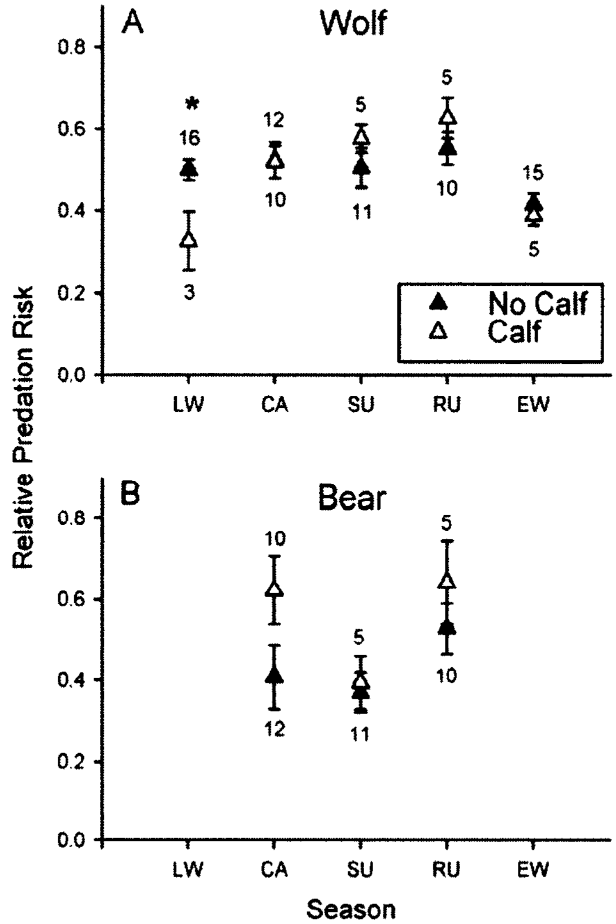


Figure 3.3. Average ($\bar{x}$± SE) seasonal predation risk by A) wolves and B) grizzly bears to female radio-collared moose in the South Canol area of south-central Yukon. LW = Late Winter, CA = Calving, SU = Summer, RU = Rut, EW = Early Winter. Numbers indicate sample size. * indicates significance difference.

Seasonal Habitat Selection

Sample size varied among individuals because of missing data for individuals. The Late Winter models were represented by the fewest moose (5 males, 7 females), whereas the Calving models were based on the most moose (8 males, 13 females). Each seasonal pooled model included elevation, aspect, predation risk, and all 8 land-cover classes; however, both the sign (+/-) and significance of the coefficients varied seasonally (Tables 3.5, 3.6).

Based on the seasonal pooled models, male moose selected for higher elevations in all seasons (as indicated by positive β_i for elevation and negative β_i for elevation^2). Female moose showed similar selection patterns except during Calving and Summer, when elevation was not a significant factor in the pooled models for habitat selection. During those 2 seasons, the most variation occurred among individual female moose. Males selected for west aspects (i.e., significant negative eastness and insignificant northness) during Calving and Early Winter (Table 3.5), and for southeast aspects (i.e., significant positive eastness and negative northness) in Late Winter. Similarly, female moose selected southeast-facing aspects during Late Winter; they selected for west aspects during the Rut and northwest aspects in Early Winter. Relative to predation risk, both male and female moose selected habitats that had significant bear risk during the Calving season. Wolf risk was often insignificant or variable between sexes.

Land-cover class also influenced habitat selection by moose in the South Canol area. Conifer was strongly avoided by both sexes in all seasons. Males also avoided Alpine, except in Summer. Females selected for Alpine during Calving, but then avoided it from Summer through Early Winter. Both sexes selected Upland Shrub areas in almost all seasons. The Lowland Shrub class was selected by both males and females in Late Winter and by

Table 3.5. Selection coefficients (Coef ± SE) in pooled resource selection models for male moose, calculated by season for 8 GPS-collared males from 2008–2010 in the South Canol area of south-central Yukon. As an indication of variability among individuals, the number of individuals that significantly selected for or against each parameter is shown under ++ or - -, respectively. Individuals with insignificant parameters in the model are shown under + and -; n/a refers to number of animals without a parameter. Significant coefficients are in bold.

Season	**Late Winter**							**Calving**							**Summer**						
Model	E[1] + A + P + L							E + A + P + L							E + A + P + L						
	Coef	**SE**	**++**	**+**	**- -**	**-**	**n/a**	**Coef**	**SE**	**++**	**+**	**- -**	**-**	**n/a**	**Coef**	**SE**	**++**	**+**	**- -**	**-**	**n/a**
Elevation (km)	**10.87**	2.10	2	0	3	0	0	**6.62**	1.49	4	1	2	1	0	**20.20**	2.20	5	0	1	1	0
Elevation (km^2)	**-6.23**	1.00	1	2	2	0	0	**-4.29**	0.71	1	1	5	1	0	**-9.95**	1.01	1	0	5	1	0
Eastness	**0.07**	0.02	2	0	2	1	0	**-0.23**	0.03	1	1	5	1	0	0.00	0.03	3	0	4	0	0
Northness	**-0.28**	0.02	0	1	4	0	0	-0.03	0.04	1	1	3	3	0	0.03	0.02	4	1	1	1	0
Wolf Risk	**0.20**	0.04	3	0	2	0	0	0.01	0.07	2	1	3	2	0	0.00	0.05	2	1	3	1	0
Bear Risk								**1.24**	0.13	7	0	0	1	0	0.05	0.04	3	1	1	2	0
Harvest risk																					
Conifer	**-0.46**	0.03	0	0	5	0	0	**-0.61**	0.05	0	0	7	1	0	**-0.47**	0.03	0	0	4	3	0
Alpine	**-0.15**	0.04	1	0	1	0	3	**-0.07**	0.04	0	0	0	2	6	0.05	0.05	2	2	1	0	2
Lowland Shrub	**0.08**	0.03	2	1	2	0	0	**0.44**	0.05	5	2	1	0	0	-0.05	0.05	2	2	3	0	0
Upland Shrub	**0.16**	0.04	3	0	1	0	1	**0.70**	0.12	4	2	1	1	0	**0.72**	0.05	6	0	0	0	1
Mixed Wood	-0.03	0.05	2	2	1	0	0	**-0.19**	0.06	1	1	4	2	0	**-0.40**	0.04	0	1	6	0	0
Riparian	**0.53**	0.04	4	1	0	0	0	**0.17**	0.06	3	2	2	1	0	**0.13**	0.05	3	1	2	1	0
Water	**0.08**	0.03	1	0	0	1	3	**-0.71**	0.13	0	1	2	1	4	0.03	0.02	1	0	1	0	5
Lowland Open	**-0.21**	0.06	1	0	2	0	2	**0.27**	0.09	1	4	1	0	2	-0.02	0.03	1	1	1	0	4
constant	**-5.99**	1.11	1	1	3	0	0	**-4.51**	0.75	1	1	5	1	0	**-11.56**	1.19	1	1	4	1	0

[1] E = elevation, A = aspect (eastness and northness), P = predation risk (wolf and grizzly bear), L = land-cover class, H = harvest vulnerability

Table 3.5. Continued.

Season	**Rut**							**Early Winter**						
Model	E + A + P + L + H							E + A + P + L						
	Coef	**SE**	**+ +**	**+**	**- -**	**-**	**n/a**	**Coef**	**SE**	**+ +**	**+**	**- -**	**-**	**n/a**
Elevation (km)	**10.20**	1.09	7	0	1	0	0	**19.74**	1.34	6	1	0	0	0
Elevation (km^2)	**-4.66**	0.42	1	0	7	0	0	**-8.66**	0.56	0	0	7	0	0
Eastness	0.01	0.02	5	0	2	1	0	**-0.09**	0.01	1	1	5	0	0
Northness	**0.25**	0.02	7	0	1	0	0	0.03	0.01	4	0	3	0	0
Wolf Risk	**-0.07**	0.03	3	0	4	1	0	0.04	0.02	2	2	2	1	0
Bear Risk	0.09	0.05	4	0	3	1	0							
Harvest risk	**-6.47**	0.86	2	0	4	0	2							
Conifer	**-0.59**	0.02	0	0	8	0	0	**-0.78**	0.03	0	0	7	0	0
Alpine	**-0.32**	0.05	1	0	5	2	0	**-0.51**	0.05	0	1	5	0	1
Lowland Shrub	0.00	0.03	4	0	3	1	0	**0.16**	0.02	5	1	-	1	0
Upland Shrub	**0.97**	0.03	8	0	0	0	0	**0.34**	0.03	5	0	1	0	1
Mixed Wood	**-0.36**	0.02	0	0	7	1	0	**-0.50**	0.04	-	0	5	2	0
Riparian	**0.48**	0.03	7	0	0	1	0	**0.95**	0.03	7	0	-	0	0
Water	**-0.29**	0.04	0	0	3	1	4	**0.43**	0.10	2	0	2	1	2
Lowland Open	**0.11**	0.04	2	0	2	0	4	**-0.09**	0.03	1	1	1	1	3
constant	**-7.14**	0.69	1	0	7	0	0	**-12.73**	0.81	0	0	6	1	0

Table 3.6. Selection coefficients (Coef ± SE) in pooled resource selection models for female moose, calculated by season for GPS-collared females from 2008–2010 in the South Canol area of south-central Yukon. As an indication of variability among individuals, the number of individuals that significantly selected for or against each parameter is shown under ++ or - -, respectively. Individuals with insignificant parameters in the model are shown under + and -; n/a refers to number of animals without a parameter. Significant coefficients are in bold.

Season	**Late Winter**							**Calving**							**Summer**						
Model	E[1] + A + P + L							E + A + P + L							E + A + P + L						
	Coef	**SE**	**++**	**+**	**- -**	**-**	**n/a**	**Coef**	**SE**	**++**	**+**	**- -**	**-**	**n/a**	**Coef**	**SE**	**++**	**+**	**- -**	**-**	**n/a**
Elevation (km)	**24.68**	4.99	6	-	-	1	-	-0.21	7.42	5	3	3	2	-	2.54	3.63	4	1	3	2	-
Elevation (km^2)	**-10.70**	2.58	-	1	6	-	-	-4.06	4.12	3	1	5	4	-	-1.27	1.69	2	3	4	1	-
Eastness	**0.11**	0.05	3	1	3	-	-	0.00	0.05	4	3	5	1	-	0.02	0.04	2	1	5	2	-
Northness	**-0.17**	0.05	3	-	3	1	-	-0.09	0.05	5	1	4	3	-	-0.06	0.04	3	2	4	1	-
Wolf Risk	0.02	0.06	2	1	3	1	-	0.00	0.14	5	1	5	2	-	0.00	0.09	3	2	3	2	-
Bear Risk								**1.55**	0.37	7	3	2	1	-	0.07	0.12	5	-	3	2	-
Conifer	**-0.10**	0.04	1	1	5	-	-	**-0.61**	0.09	1	1	8	3	-	**-0.11**	0.05	3	2	4	1	-
Alpine	0.00	0.00	-	-	-	1	6	**0.21**	0.10	1	3	1	-	8	**-0.35**	0.06	-	-	2	-	8
Lowland Shrub	0.09	0.05	5	1	1	-	-	0.14	0.09	7	4	1	1	-	0.04	0.04	1	3	2	4	-
Upland Shrub	-0.01	0.02	1		1	1	4	**0.54**	0.11	3	3	-	-	7	**0.32**	0.05	3	2	-	-	5
Mixed Wood	-0.05	0.05	1	1	3	2	-	**0.13**	0.06	3	4	-	4	2	**0.15**	0.05	5	1	1	2	1
Riparian	**0.18**	0.06	5	-	2	-	-	-0.01	0.09	5	4	1	3	-	**0.27**	0.07	6	1	2	1	-
Water	0.00	0.00	-	-	-	-	-	**-0.24**	0.07	-	2	2	2	7	**-0.16**	0.05	-	1	3	1	5
Lowland Open	**-0.10**	0.02	-	-	1	-	6	**-0.15**	0.05	-	-	2	2	9	**-0.15**	0.04	-	-	2	1	7
constant	**-15.71**	2.49	-	1	6	-	-	-0.10	3.47	2	2	6	3	-	-3.39	1.89	2	2	5	1	-

[1] E = elevation, A = aspect (eastness and northness), P = predation risk (wolf and grizzly bear), L = land-cover class, H = harvest vulnerability

Table 3.6. Continued.

Season	**Rut**							**Early Winter**						
Model	E + A + P + L + H							E + A + P + L						
	Coef	**SE**	**+ +**	**+**	**- -**	**-**	**n/a**	**Coef**	**SE**	**+ +**	**+**	**- -**	**-**	**n/a**
Elevation (km)	**10.31**	1.76	5	2	3	-	-	**6.97**	0.69	8	-	2	-	-
Elevation (km^2)	**-4.06**	0.72	3	-	5	2	-	**-3.30**	0.28	1	1	8	-	-
Eastness	**-0.06**	0.02	2	2	6	-	-	**-0.11**	0.02	2	1	5	2	-
Northness	-0.04	0.02	4	-	6	-	-	**0.10**	0.03	7	-	3	-	-
Wolf Risk	**0.50**	0.08	6	2	-	2	-	**0.07**	0.03	4	2	4	-	-
Bear Risk	-0.05	0.08	5	2	1	2	-							
Harvest risk														
Conifer	**-0.24**	0.03	1	1	6	2	-	**-0.64**	0.04	-	-	9	1	-
Alpine	**-0.34**	0.08	2	1	4	1	2	**-0.79**	0.09	1	2	6	-	1
Lowland Shrub	-0.02	0.07	7	-	3	-	-	**0.22**	0.03	7	-	1	2	-
Upland Shrub	**0.42**	0.07	7	1	2	-	-	**0.49**	0.05	6	2	1	1	-
Mixed Wood	-0.11	0.06	2	2	4	2	-	**-0.24**	0.05	1	1	5	3	-
Riparian	**0.38**	0.05	7	1	2	-	-	**0.66**	0.03	9	1	-	-	-
Water	**-0.14**	0.04	1	1	2	1	5	**-0.10**	0.02	-	-	2	1	7
Lowland Open	0.04	0.04	2	1	2	1	4	0.39	0.05	5	-	1	1	3
constant	**-8.49**	1.06	2	1	6	1	-	**-5.30**	0.42	1	-	9	-	-

males in the 2 seasons before and after (Calving and Early Winter). Mixed Wood was almost always avoided by males, but selected by female moose during Calving and Summer. Both sexes always selected for Riparian areas (although not significantly by females during Calving). Female moose selected against Water, and the influence of Water varied across seasons for males, with positive selection for frozen waterways in Early and Late Winter.

For models developed for females with and without a calf, there were only 7 valid models after k-fold cross-validation (out of 24; 6 models for each animal) to explain habitat selection during Calving for 4 females with known calf status. Six of these models had AIC_c weights <0.95. Three models would have resulted from model averaging, but given the very low sample sizes (2 females with calves, 2 without), we did not pursue further analysis. The only consistency observed in those models was selection for Lowland Shrub by all 4 females. Additionally, females with calves selected for higher elevations while avoiding Mixed Wood. Females without a calf selected Mixed Wood and avoided Riparian.

Variation in Seasonal Habitat Selection among Individual Moose

For the 24 individual moose in our study, 82 final models described seasonal habitat selection (Appendix F, G). In addition to all topographic and predation coefficients, there were at least 3 land-cover classes (i.e., Conifer, Lowland Shrub, Riparian) in all final models. As mentioned above, in the averaging process for gender-specific pooled models, Late Winter had the fewest explanatory models and because of missing data for individuals Calving had the most. In general, there were more individual models during Summer and Rut for males than for females.

There were some strong seasonal trends among individual moose within a sex. Female patterns tended to be more variable than males, particularly during Calving.

Responses to east-facing slopes, wolf risk, and the Water and Lowland Open classes were highly variable among individuals.

During Late Winter, most individuals selected for Riparian areas and avoided Conifer stands. Individuals by sex responded to Mixed Wood differently; most males selected it while most females avoided it. Most male moose avoided north-facing slopes, but responses to aspect were highly disparate among females. At this time, when snow was presumed to be deepest, most females selected for Lowland Shrub areas, whereas there was more variability among males.

During the Calving season, most individuals continued to avoid Conifer and were often in high bear-risk areas. Most males continued to avoid north-facing slopes and selected Lowland and Upland Shrub areas. Females were highly variable in their use of land-cover classes during Calving.

In Summer, male moose selected more consistently for mid-elevations than during Late Winter and Calving, and avoided Conifer cover. The selection for Conifer and Lowland Shrub classes was more variable among individual females in Summer than in other seasons.

Not surprisingly, male and female individuals displayed most similarities during the breeding season and the post-rut period. During Rut and Early Winter, most individuals selected Upland Shrub and Riparian areas while strongly avoiding Conifer. The majority of male moose avoided Alpine and Mixed Wood during the Rut. Most individuals of both sexes selected for Lowland Shrub in Early Winter.

DISCUSSION

Moose are a keystone species of northern boreal forests, playing important roles in predator-prey dynamics and forest succession (Molvar *et al.* 1993, Danell *et al.* 1998). The large geographic range of moose is a reflection of their ability to utilize a wide variety of habitats. Elevation, aspect, predation risk, and land cover all had significant effects on seasonal habitat selection by moose in the South Canol area. Despite a high level of individual variation throughout the year, the strongest seasonal selection patterns became obvious when the majority of individuals within a sex consistently selected or avoided a particular variable.

Elevational differences in temperature and soil moisture influence habitat selection through associated changes in vegetation, snow depth and thermal conditions. In an effort to balance energetic demands, moose respond to the changing quantity and quality of forage species and accessibility to forage and cover that are found along elevation gradients (Stumph and Wright 2007). Male moose in our study selected for elevation in all seasons, and most consistently among individuals in Summer, Rut and Early Winter. Access to the higher elevations in these seasons (as reflected in use patterns, Chapter 2: Fig. 2.3) may play an important role in the survival strategies of male moose in south-central Yukon. Ballard *et al.* (1991) reported that upland sites had higher quantities of browse, but lower elevation sites had greater availability as winter progressed. In our study area, upland areas may provide similar opportunities for moose to maximize forage intake in the seasons surrounding Rut, and to build adequate fat reserves before the snowpack forces them to move down in Late Winter (Chapter 2). Like males, female moose also selected for elevation in most seasons, except during Calving and Summer when strategies varied among individuals. Oehlers *et al.*

(2011) reported moose calving at lower elevations in southeast Alaska, which contrasted with female moose in interior Alaska that chose high-elevation birth sites (Bowyer *et al.* 1999). Female moose in southeast British Columbia were categorized as "climbers" or "non-climbers" during the Calving season (Poole *et al.* 2007). These examples, as well as the variation in individual models in our study, highlight the unpredictable nature of birth-site selection by females during Calving.

Similar to elevation, aspect can strongly influence ambient temperature and soil moisture. South-facing slopes receive the most solar radiation and are the first to green up at northern latitudes; north-facing slopes tend to be cooler and moister throughout the year. East and west aspects increase solar insolation at different times of the year. In the South Canol area, we observed that male moose (both as a group and individually) selected for west aspects during Calving and Early Winter. Female moose selected northwest aspects in Early Winter, but there was greater individual variation. This selection may reflect a need to minimize heat stress during times of the year when moose have highly insulative winter pelage and temperatures may occasionally be relatively warm. Males and females selected southeast aspects during Late Winter, when the males in particular must minimize energy losses in order to survive until spring. Similar to our findings in Late Winter, moose in southeast British Columbia preferred gentler slopes with high solar insolation during late winter (Poole and Stuart-Smith 2006) and moose in Montana selected south- and west-facing aspects in late winter (Langley 1993). Selection of south-facing slopes may allow moose to key in on spring green-up. Bowyer *et al.* (1999) reported that female moose preferred to give birth on southeast exposures where soils were drier and forage was of higher quality.

We defined predation risk for moose in the South Canol area of Yukon by combining habitat information from our study area with seasonal RSFs from GPS-collared wolves and grizzly bears in the Besa-Prophet area of northern British Columbia. These models were assumed to be compatible with our landscape based on similar predator species, climate, and mountainous topography. The predation risk surfaces, however, should be tested with local predator data as they become available and because the prey base in the South Canol area is not as diverse as that in the Besa-Prophet area of northern British Columbia. Reducing exposure to mortality risk has obvious benefits to individual moose survival. Associated with predators, there also can be energetic costs such as reduced foraging efficiency caused by increased vigilance or movement, and by choosing safer habitats that may have less forage (Molvar and Bowyer 1994, White and Berger 2001, Montgomery *et al.* 2013 a, b). Additionally, Kunkel and Pletcher (2000) noted that wolf kill rates increased with increasing distance to cover, decreasing road density, increasing trail and stream density and increasing wolf density.

In the South Canol area, exposure to predation risk varied seasonally, but not between males and females. Individual responses, however, were variable. Contrary to our hypothesis, females did not avoid predation risk during the Calving season. Both females and males showed positive selection for areas with higher bear risk during Calving, presumably by taking advantage of areas with earlier green-up that were also frequented by bears. Females with calves, however, tended to be in areas with lower bear risk than females without calves. During Late Winter, female moose with calves also used areas with significantly less wolf risk than females without calves. Because of their shorter legs, moose calves are more vulnerable in deep snow than adults (Peterson and Allen 1974, Peterson 1977). Females with calves are known to reduce wolf risk by staying closer to cover, which helps make calves less visible and where snow depths may be lower (White and Berger 2001). Male moose in the South Canol area avoided wolf risk during Rut, but their exposure to wolf risk (as indexed by average relative risk; Fig. 3.2) was slightly higher during Rut than during the Calving season or Summer. During the moose breeding season, wolf pups (and the associated adults) are more mobile than earlier in the growing season, potentially increasing risk to moose (Mech 1970, Mills *et al.* 2008). During Rut, exposure to bear risk for both sexes was significantly higher than during Summer. This is likely because bears move up in elevation in late summer and fall to target the rich berry crop that can often be found in subalpine areas. By Early Winter, exposure to bear risk was negligible as bears hibernated. Average exposure to wolf risk (Fig. 3.2) dropped significantly; the positive selection coefficients in the pooled models for both sexes may indicate simply those areas also frequented by wolves rather than high-risk areas per se.

In Yukon, most moose harvest targets male moose and most hunting pressure occurs in September (Yukon Department of Environment 2008).We expected males to select areas with lower harvest vulnerability during Rut and analysis confirmed that males as a group minimized harvest vulnerability. The individual responses, however, were variable and only 50% of males avoided this risk. The selection for less-accessible higher elevations during Rut may have served to reduce exposure to harvest vulnerability as well as predation risk. Because of limited road access, most moose harvested in our study area were harvested at lower elevations, often on or within 500 m of large waterways. Similarly in Quebec, density of hunting camps, length of large rivers, and surface area of lakes had the greatest effects on harvest vulnerability (Courtois and Beaumont 1999). Male moose may also make fine-scale adjustments to avoid detection, but such selection or avoidance would be difficult to determine at the resolution (25 m) of our study (Courtois and Beaumont 1999, Laurian *et al.* 2000). Vulnerability and response to harvest risk can vary depending on age and experience of the moose. In our study, only mature males were collared and individuals likely had several years' experience avoiding detection by predators or humans. Habitat selection by younger males may differ from our observations.

We expected moose to maximize forage intake during the growing season (Belovsky 1978) and minimize energy losses in winter, recognizing that male and female moose would likely use different strategies to meet those ends. We assumed a forage-based strategy would be indicated by strong selection for shrub-dominated land-cover classes, whereas selection of Conifer would indicate a greater need for cover. In the South Canol area, all male moose avoided Conifer throughout the year. Females, as a group, also avoided Conifer in all seasons, although individual females were more variable in their response. The interpretation of strategies used for forage and cover may be confounded by the scale of selection and because Conifer made up a large proportion of our study area (Chapter 2). Even though Conifer was avoided, because of its abundance on the landscape it was still used often. Poole and Smith (2006) reported that moose selected higher crown closure at the landscape scale, whereas others have observed selection by moose for conifer stands at finer scales related to thermal cover (McNicol and Gilbert 1978), forage diversity (Peek 1997), and predation risk (Bowyer *et al.* 1999, Dussault *et al.* 2004, Bjorneraas *et al.* 2011). Throughout most of the year, male and female moose selected for shrub-dominated land-cover (i.e., Upland Shrub, Riparian, or Lowland Shrub). For both sexes, greatest selection was for the Upland Shrub class during the Calving season through Rut and for Riparian areas in Early and Late Winter.

Most individuals also selected for Lowland Shrub from Early Winter through Calving. The elevational gradient encompassed by these communities likely enabled both males and females to target areas with highest food quality and forage biomass, depending on season.

We expected selection patterns of both sexes to be most similar during the breeding season and most different during parturition and lactation (Miquelle *et al.* 1992, Oehlers *et al.* 2011). Indeed, during Rut both males and females selected strongly for Upland Shrub and Riparian, while avoiding Conifer, Alpine, and Water. During Calving, male and female moose generally differed in their response to Alpine, Riparian, Water and Lowland Open classes. Interestingly, during the Calving season females did not select for Riparian areas. This observation was surprising given that the proximity to water is an important characteristic of birth sites in other areas (Oehlers *et al.* 2011). We defined riparian zones as areas within 100 m (4 pixels) of large rivers and lakes and only 25 m (1 pixel) from small streams, so perhaps females were able to locate birth sites outside of the riparian zone as we defined it, but still with adequate access to water during that time.

Land-cover classification based on satellite imagery is efficient and was particularly valuable in our study which spanned a remote and isolated area covering 14% of Yukon's landmass. An existing EOSD land-cover classification for Yukon had a species-appropriate resolution (25 m) and was based on digital imagery collected within 8 years of the study. By merging some of the 24 classes into 8, we reduced the chances for misclassification. The variation encompassed by each land-cover class, however, may have contributed to the variation observed among individuals and could be important in fine-scale selection by moose.

Variation in selection patterns also may have been confounded by the GPS locations for each individual. Although we could not adjust for potential bias in fix rates, we reduced bias toward particular individuals with more location fixes by developing selection models per individual, and requiring a minimum of 100 locations per individual per season. We also had the opportunity to monitor a stationary fully-functioning GPS collar for 11 months (after an animal died) to assess GPS field accuracy. Mean distance between fixes was 7.9 ± 0.25 m. Given the resolution of the land-cover data, the land-cover class associated with each location point was fairly precise.

GPS fix rates were quite low for one model of collar. These low fix rates may have introduced location bias, particularly if missed fixes were more likely to occur in some land-cover classes. As discussed in Chapter 2 (and see Frair *et al.* 2004, Nielson *et al.* 2009), there is no method to correct for missing fixes, particularly when the geographic space they represent is important. It is most likely that any biases are associated with under-representing the use of closed conifer forests and perhaps north-facing aspects. There was, however, no significant relationship between fix-rate success and the proportion of Conifer land cover within annual ranges across collared individuals or among individuals with collars from the same manufacturer. Lowest (18% of annual range) and highest (66%) Conifer cover were both observed with fix rates >88%. Nonetheless, our habitat selection coefficients should be interpreted with caution in the possible case of alternative biases.

Conclusions and Implications

Moose in south-central Yukon altered their selection strategies in response to seasonal changes typical of northern boreal forests. Differential seasonal selection was observed within individuals and groups. Gender differences in exposure to risk were not supported by our data, but may occur at finer spatial and temporal scales than in our study.

Differences in the selection coefficients of individual and pooled models underscored the variety of moose-habitat relations in the South Canol area. Pooled models for large non-herding species such as moose may encompass highly variable behaviour among individuals. The "average" moose may not exist (Gillingham and Parker 2008). Individual models can, however, demonstrate the variability *within* the population of interest. Relative consistency of individual responses within a gender supports trends identified by pooled selection coefficients, as well as detects trends between sexes.

In south-central Yukon, seasonal climatic factors influenced the selection options available to moose at critical times of the year. These options may be particularly important for moose populations in Yukon, where climate change is believed to be occurring more rapidly than in more southerly locations (ACIA 2005). In a warmer climate, moose experience increased heat stress, higher parasitic loads, more malnutrition, and greater wolf predation (Rempel 2011). Moose respond to climatic factors at large scales (Hallett *et al.* 2004); and therefore, may be affected over broad areas. Declines in moose populations have already been observed at the southern reaches of moose range in recent years (e.g., Post *et al.* 1999, Murray *et al.* 2006). Less is known about the effect of climate change on northern moose populations.

Chapter 4: Research implications and recommendations for managing moose (*Alces alces*) in south-central Yukon

INTRODUCTION

Moose are integral to all Yukon communities, offering subsistence, cultural, economic, and recreational values. The distribution of moose in Yukon reaches some of the most northern limits of the species' range; they experience an extreme range of thermal conditions, highly variable snow depths, and predation and hunting pressure. Additionally, because of relatively low productivity, Yukon landscapes and their corresponding wildlife populations may be more vulnerable to disturbance, take longer to recover, and respond in ways not typical of more southern landscapes. The South Canol moose study was initiated in response to concerns about the potential effects of future development, changing harvest rates, and unregulated predator populations on the survival of local moose populations. My goal was to augment existing local knowledge with scientific data to better understand the seasonal strategies of male and female moose in a dynamic boreal landscape.

In this chapter, I summarize my findings from the South Canol moose study, particularly in the context of documented local knowledge and previous post-rut moose studies (McLeod and Clarke 2011, Clarke 2013). I then provide recommendations on how to incorporate these insights into existing moose-management guidelines to ensure that adequate distribution of suitable moose habitat is maintained, harvest rates are sustainable, and local communities and interest groups have enhanced opportunities to contribute knowledge towards management of this keystone species. Finally, I provide direction for future moose research in south-central Yukon.

PROJECT SUMMARY

Over a two-year period during my study, ~80,000 location points were collected from 24 male and female GPS-collared moose in a 35,000 km^2 area in south-central Yukon. I combined those data with remotely-sensed landscape information to examine habitat use and selection by males and females over different spatial and temporal scales. Like other ungulates, moose require access to adequate forage, cover, and reproductive opportunities. Forage quality and quantity can be related to land-cover class (e.g., shrub-dominated areas generally offer more forage for moose than conifer stands or alpine areas). Cover is used for concealment from predators, moderates environmental conditions, and is influenced by land-cover class, elevation and aspect. Wolves (*Canis lupus*) and grizzly bears (*Ursus arctos*) are the dominant predators of immature and adult moose. Exposure to predation risk varies over the landscape and throughout the year. Most moose harvest occurs during the Rut season and targets male moose (although light harvest of both sexes can occur at anytime of the year by members of First Nations).

I observed different patterns in range size, movement rates, and use of elevation and land cover among individual telemetered moose, but differences between males and females, and between females with and without a calf were not statistically significant. In contrast, seasonal changes did have a significant effect on range sizes, movement rates, and elevation and land-cover use of these groups. Based on use of lower elevations and lower movement rates, snow depth appears to be the dominant limiting factor for moose during Late Winter. Use was high in shrub-dominated land-cover classes, which presumably supplied critical winter forage. During the Calving season, Conifer and Water were more important classes. In Summer, females made frequent short movements within small ranges; perhaps as a predator avoidance strategy. Moose used the highest elevations during Rut and Early Winter. Males also had the highest movement rates during Rut. Patterns in use data, however, do not provide information on whether moose actually selected locations because of a particular characteristic (or set of characteristics), or whether they were encountered during movements within ranges.

To complement measures of use, I calculated individual resource selection function (RSF) models to compare the use of land cover, topography, predation risk, and harvest vulnerability variables in relation to their availability. Land cover was mapped across the landscape and was based on 8 classes in the South Canol area (Fig. 4.1). Topography included elevation, slope, and aspect and was derived from a digital elevation model (DEM). Predation risk was inferred from resource selection values based on wolf and grizzly bear studies in northern British Columbia and was mapped across the study area (Fig. 4.2). I also mapped harvest vulnerability based on harvest location data provided by hunters (Fig. 4.3). Selection for a variable was indicated if it was used in greater proportion than it was available, whereas avoidance was indicated if a variable was used less often than available. I defined availability by selecting 5 random points for each telemetry use location from within a buffer representing the 95^{th} percentile seasonal movement rate for each moose. Eighty-two valid models explained habitat selection across 5 seasons for 24 moose. All topographic variables (elevation, elevation^2, and aspect) and at least 3 land-cover classes (i.e., Conifer, Lowland Shrub, and Riparian) were included in all valid models. Valid models were those that showed good correspondence between predictions and use. The number of valid models across individuals was greatest for the Calving season, and the fewest valid models were for Late Winter. Selection was most similar among individuals during Early Winter and most

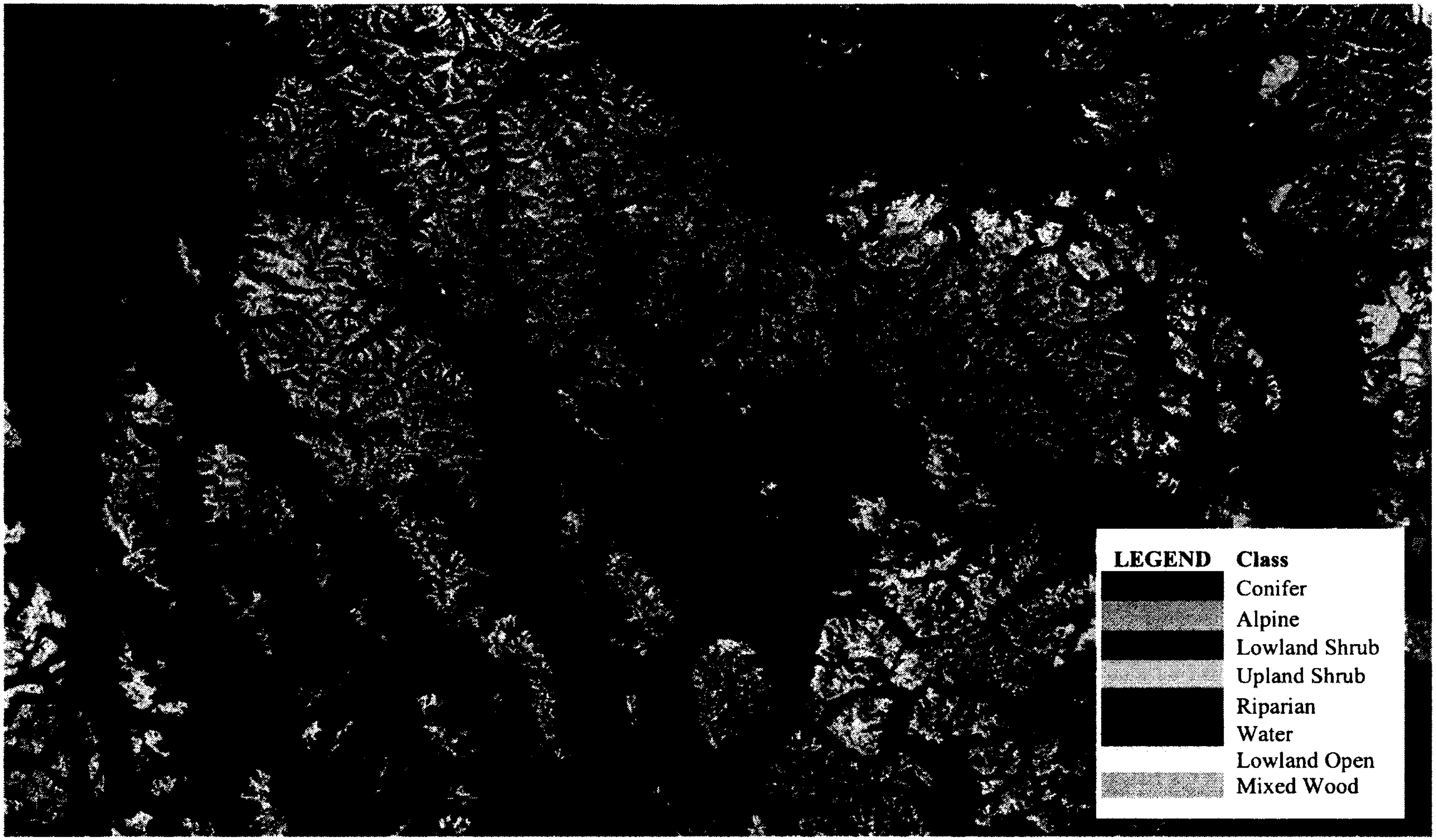


Figure 4.1. Distribution of 8 land-cover classes available to moose across the South Canol study area.

A) Grizzly Bear Risk

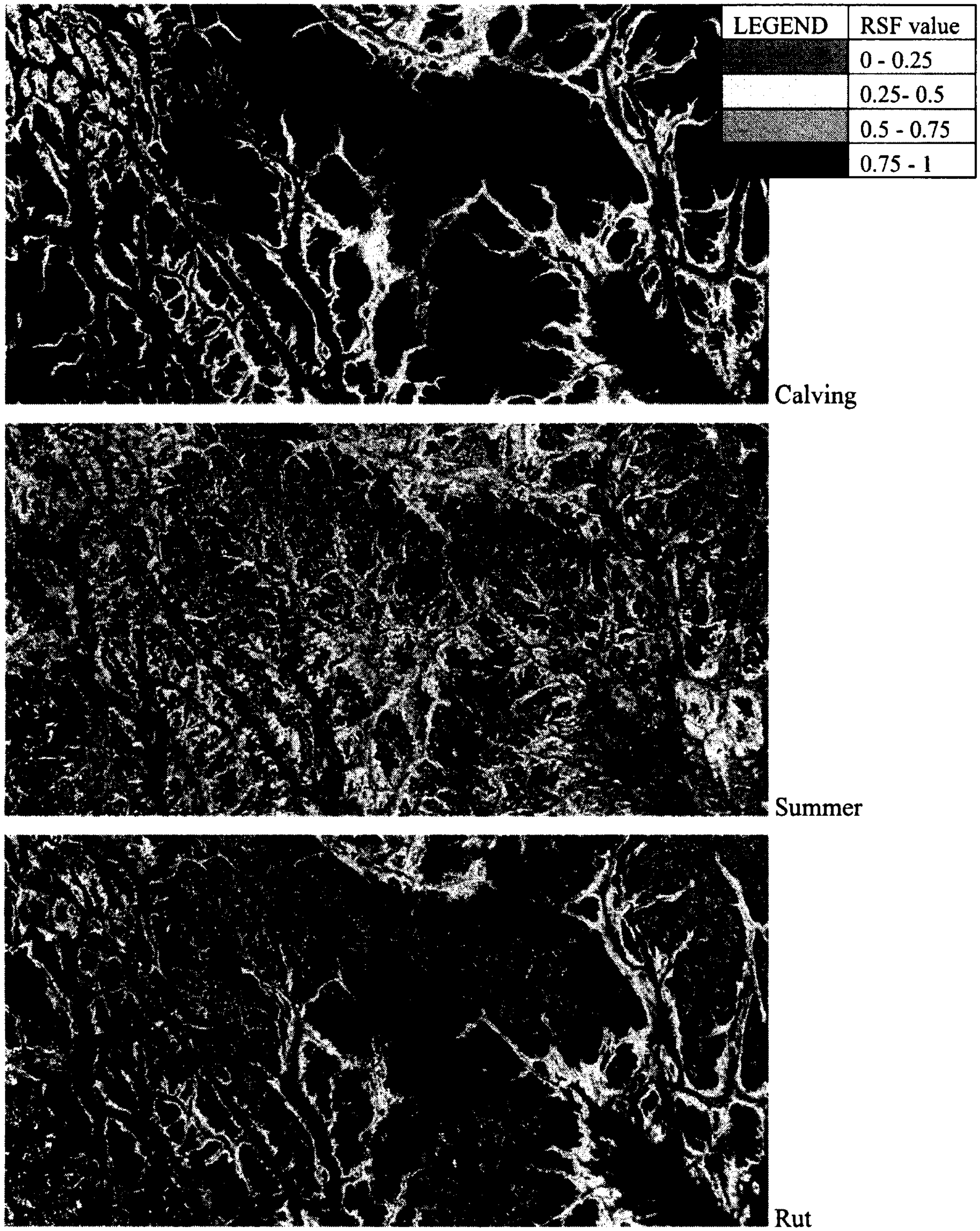


Figure 4.2. Relative A) grizzly bear, and B) wolf predation risk to moose by season in the South Canol area of south-central Yukon. Predation risk was based on attributes in resource selection models for wolves and grizzly bears in northern British Columbia (Milakovic 2008).

B) Wolf Risk

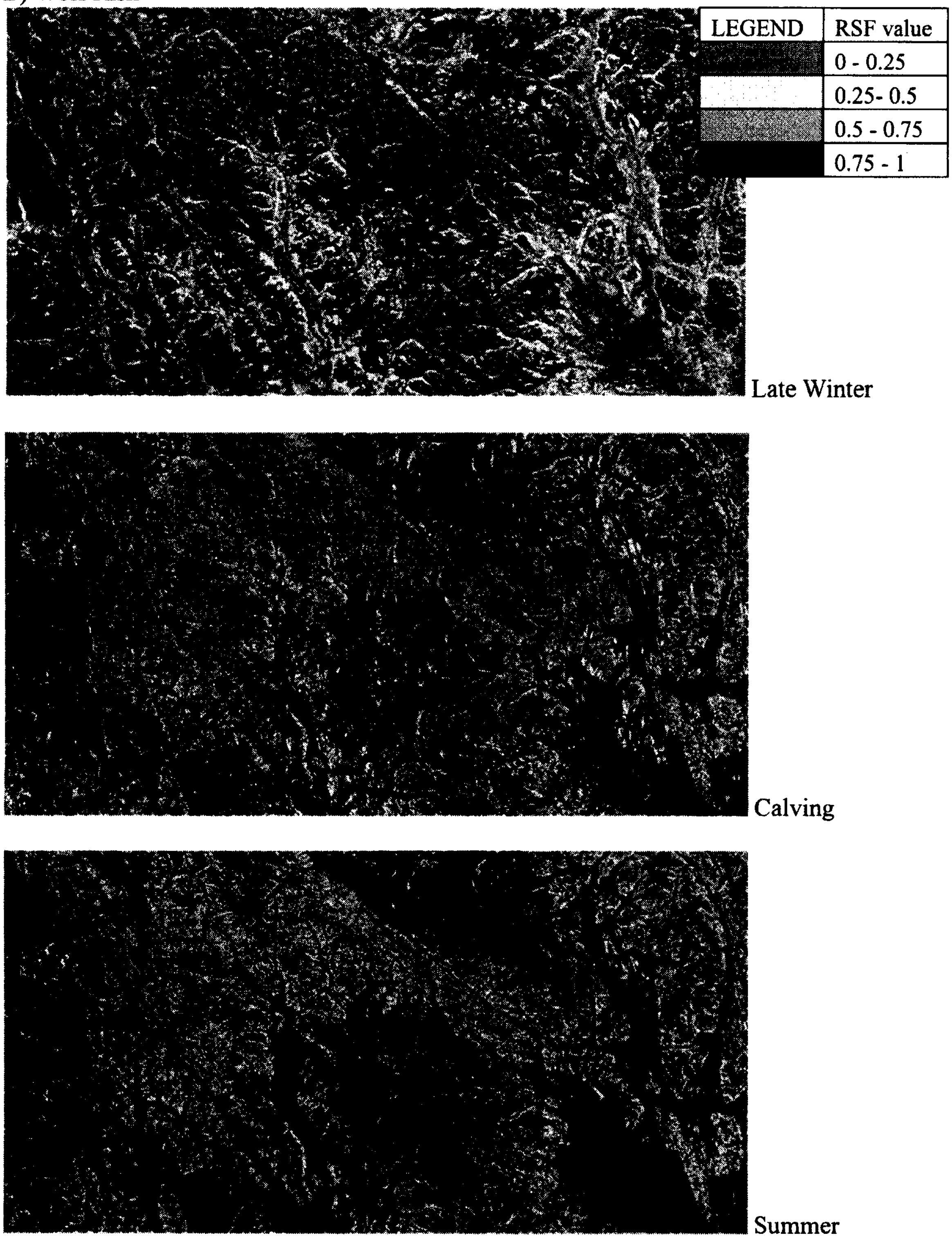
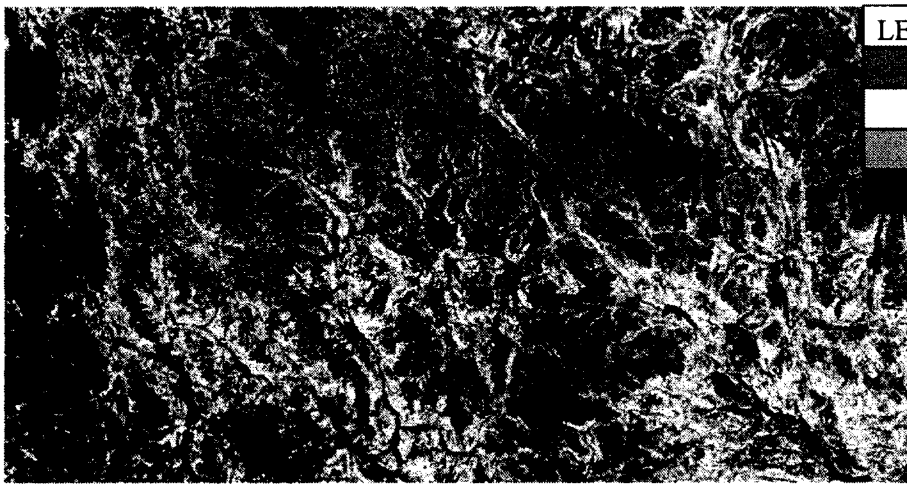


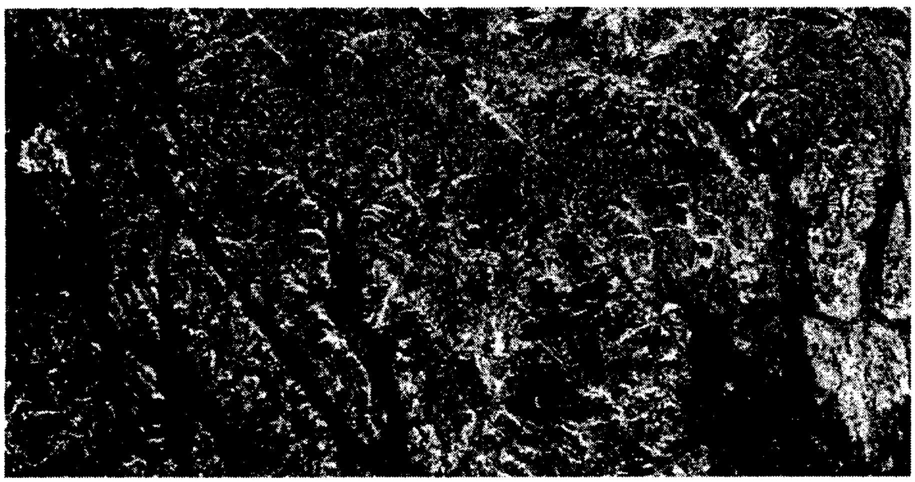
Figure 4.2. Continued.

B) Wolf Risk



LEGEND	RSF value
	0 - 0.25
	0.25- 0.5
	0.5 - 0.75
	0.75 - 1

Rut



Early Winter

Figure 4.2. Continued.

Figure 4.3. Relative harvest risk to male moose during Rut in the South Canol area of south-central Yukon. Harvest risk was based on harvest location data provided by hunters.

variable during Calving, based on model coefficients.

Forage appears to be the primary force driving seasonal selection patterns of moose in the South Canol area, as evidenced by high use and positive selection for shrub-dominated classes such as Lowland Shrub and Riparian by all individuals in all seasons. High use but avoidance of Conifer by most individuals in all seasons indicated that cover was likely more influential at a different scale than examined in this study. Response (use and selection) to mortality risk (predation and harvest) was variable among individual moose.

By interpreting selection results within the context of use data, the scale(s) at which moose make habitat choices became more apparent. Opposing use and selection trends seemed to indicate that resource decisions were being made at different scales. High use of a resource that was avoided may have resulted from an overall abundance of that resource, indicating that it may be important across a broader scale. For example, in contrast with the use data, RSF models (Chapter 3) indicated that Conifer cover was avoided by all moose. The high use of Conifer presumably occurred because it was so widespread on the boreal landscape. At the smaller scale of the seasonal home range, however, moose selected against conifer stands in favour of land-cover classes assumed to have better forage availability (e.g., Lowland Shrub). If a resource was selected (as indicated by a positive coefficient in the RSF), but use was low (as per telemetry locations), that resource was probably relatively rare at that scale. If use and selection were examined at a finer scale than the seasonal range (e.g., stand scale), use and selection would likely be more parsimonious. Similar use and selection results highlighted important variables at the seasonal scale.

Pooled selection models (average of best individual models) were estimated for male and female moose to get a sense of the different selection strategies used by male and female moose. Some selection patterns were similar between males and females. Conifer was avoided by both sexes in all seasons. In most seasons (except for Late Winter), both sexes selected Upland Shrub and higher elevations. Additionally, riparian areas were important to male and female moose during the Rut and winter seasons. There was, however, a high degree of individual variation. The more variation in the data, the harder it is to detect differences among groups or to produce robust pooled models. In the South Canol data, the greatest amount of individual variation occurred during the growing season (Calving and Summer) and the least amount during Late Winter, suggesting that climatic factors limited the options available to moose at a critical time of the year. This observation may have important implications to moose populations in Yukon, where climate change is occurring at a faster pace than in more southerly moose ranges.

INTEGRATION OF STUDY FINDINGS WITH EXISTING DATA

Traditional and Local Knowledge

Scientific studies, in general, excel at collecting detailed spatial information on individual animal behaviour, whereas local and traditional knowledge tends to excel at identification of ecological relationships over longer periods of time. Both types of information are useful for better delineation of moose habitats. Therefore, the integration of scientific studies with local and traditional knowledge is important to the long-term management of moose in Yukon. Yukon First Nations have clearly established rights to participation in wildlife management processes and decisions under the Yukon First Nations Umbrella Final Agreement (UFA) (signed in 1993, *Yukon First Nation Settlement Agreement Act* 1994) and/or individual First Nations Final Agreements. For the most part, the main vehicles for participation have been through Renewable Resource Councils and related management boards. What is less clearly outlined, however, is how to effectively engage local communities and the best methods for establishing open relationships to facilitate the exchange of information on wildlife species and their management.

Using GPS telemetry data, I was able to monitor individual moose behaviour at a 25-m resolution over a large and remote area. These location data were costly to collect, relatively limited in scope (i.e., 2 years, 24 individuals), and presumably not error-free. The technological limitations and relatively short time-line of this research are typical of western-based scientific studies. The dependence on moose by Yukon communities has resulted in the accumulation of extensive traditional and local ecological knowledge about moose throughout the territory. This community knowledge base can complement and enhance current and future science-based research (Riedlinger 1999). Incorporating such alternative forms of knowledge into moose management provides greater breadth and depth of environmental information and a more holistic understanding of ecological relationships (Huntington 2000). This is particularly relevant in remote areas that make up much of the boreal forest in Yukon.

South Canol Knowledge-based Habitat Suitability

Concurrent with my study, a local knowledge-based habitat suitability index (HSI) was created for a core portion of the study area by Yukon Department of Environment (McLeod and Clarke 2011) using the knowledge and experience of hunters, trappers and biologists familiar with the area and/or who had spent extensive time on the land. Local knowledge often spanned decades, but tended to be limited to a few key areas (mainly hunting areas and travel routes). Participants were asked to rank land-cover classes for moose based on colour reference photos using a four-class ranking system: 0 (not important), 1 (may be important), 2 (fairly important) and 3 (very important). Based on these interviews, different combinations of land-cover classes were used to define 4 HSI ranks for 3 moose groups (males, females with calves, females without calves) and 5 seasons (Table 4.1, from McLeod and Clarke 2011).

The GPS telemetry data set from my study provided an opportunity to test if radio-collared moose behaved in ways predicted by the local knowledge-based HSI developed by Yukon Department of Environment. I calculated the percentage of GPS locations in each of their HSI ranks for data by moose group and season. To account for different land-cover availability, I adjusted these values by the proportion of each rank available in my total study area (Fig. 4.4). Local knowledge did not always identify a rank for each season and group, so GPS locations could not be compared in some ranks (e.g., medium suitability for males during Rut). I expected that use would increase as the HSI rank increased: the greatest percentage of locations should be in classes assessed as higher suitability. With a few exceptions, this was the case.

The area-adjusted GPS locations of male and female moose (with and without a calf) occurred more often in land-cover classes with higher HSI ranks, especially during the Calving season. Males in particular followed this expected pattern in most seasons except Early Winter, when all groups used areas of medium HSI value more than high suitability. For males and females without calves, medium HSI value was defined by Riparian land cover, whereas high suitability was defined by Upland and Lowland Shrub. Combined with data showing that moose used highest elevations during Rut and Early Winter (Chapter 2: Fig. 2.2, 2.3), it seems likely that male and female moose without calves were targeting the

Table 4.1. Summary of knowledge-based habitat suitability index (HSI) ranking for moose by season in the South Canol area of south-central Yukon (McLeod and Clarke 2011). Land-cover classes are defined in Appendix A.

		HSI Ranking			
Group	**Season**	**High**	**Medium**	**Low**	**Nil**
Males	Early Winter	Upland Shrub, Lowland Shrub	Riparian	Wetland, Deciduous, Mixed Wood, Conifer	Water, Alpine, Lowland Herb, Lowland Non-vegetated
	Late Winter	Riparian, Wetland, Lowland Shrub	Mixed Wood	Deciduous, Conifer	Water, Alpine, Lowland Herb, Lowland Non-vegetated, Upland Shrub
	Calving	Riparian, Wetland	Upland Shrub, Lowland Shrub	Deciduous, Mixed Wood, Conifer, Lowland Herb	Water, Alpine, Lowland Non-vegetated
	Summer	Riparian, Water, Wetland, Upland Shrub, Lowland Shrub	n/a	Deciduous, Mixed Wood, Conifer, Lowland Herb	Alpine, Lowland Non-vegetated
	Rut	Riparian, Wetland, Upland Shrub, Mixed Wood, Lowland Shrub	n/a	Deciduous, Conifer, Lowland Herb	Water, Alpine, Lowland Non-vegetated
Female	Early Winter	Upland Shrub, Lowland Shrub	Riparian	Wetland, Deciduous, Mixed Wood, Conifer	Water, Alpine, Lowland Herb, Lowland Non-vegetated
	Late Winter	Riparian, Wetland	Mixed Wood, Lowland Shrub	Upland Shrub, Deciduous, Conifer	Water, Alpine, Lowland Herb, Lowland Non-vegetated
	Calving	Riparian, Water, Wetland, Mixed Wood, Lowland Shrub	n/a	Upland Shrub, Deciduous, Conifer, Lowland Herb	Alpine, Lowland Non-vegetated
	Summer	Riparian, Water, Wetland	Upland Shrub	Deciduous, Mixed Wood, Conifer, Lowland Shrub, Lowland Herb	Alpine, Lowland Non-vegetated
	Rut	Riparian, Water, Wetland, Upland Shrub, Mixed Wood, Lowland Shrub	Conifer	Deciduous, Lowland Herb	Alpine, Lowland Non-vegetated

Group	Season	High	Medium	Low	Nil
Females with Calf	Early Winter	Upland Shrub	Lowland Shrub	Wetland, Deciduous, Mixed Wood, Conifer, Riparian	Water, Alpine, Lowland Herb, Lowland Non-vegetated
	Late Winter	Riparian, Wetland, Mixed Wood, Lowland Shrub	n/a	Deciduous, Conifer	Water, Alpine, Lowland Herb, Lowland Non-vegetated, Upland Shrub
	Calving	Riparian, Water, Wetland, Mixed Wood	n/a	Upland Shrub, Deciduous, Conifer, Lowland Shrub, Lowland Herb	Alpine, Lowland Non-vegetated
	Summer	Riparian, Water, Wetland, Mixed Wood, Lowland Shrub	Upland Shrub	Deciduous, Conifer, Lowland Herb	Alpine, Lowland Non-vegetated
	Rut	Riparian, Water, Wetland, Upland Shrub, Lowland Shrub	Mixed Wood, Conifer	Deciduous, Lowland Herb	Alpine, Lowland Non-vegetated

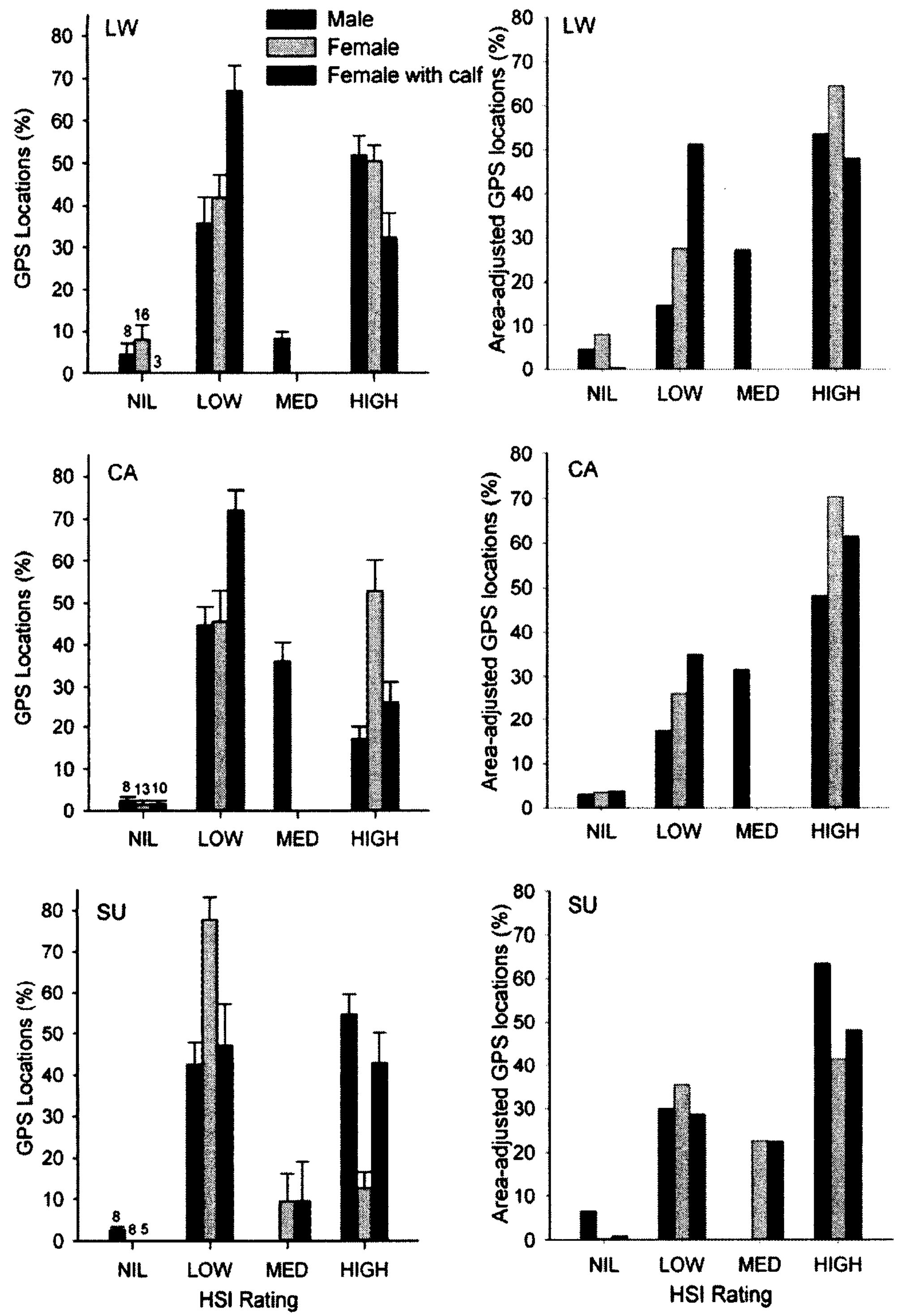


Figure 4.4. Percent ($\bar{x}$ ± SE) of GPS locations and area-adjusted GPS locations of radio-collared moose by group and season in each of 4 HSI (habitat suitability index) ranks, as identified by local and traditional knowledge (McLeod and Clarke 2011), in the South Canol area of south-central Yukon. LW = Late Winter, CA = Calving, SU = Summer, RU = Rut, EW = Early Winter.

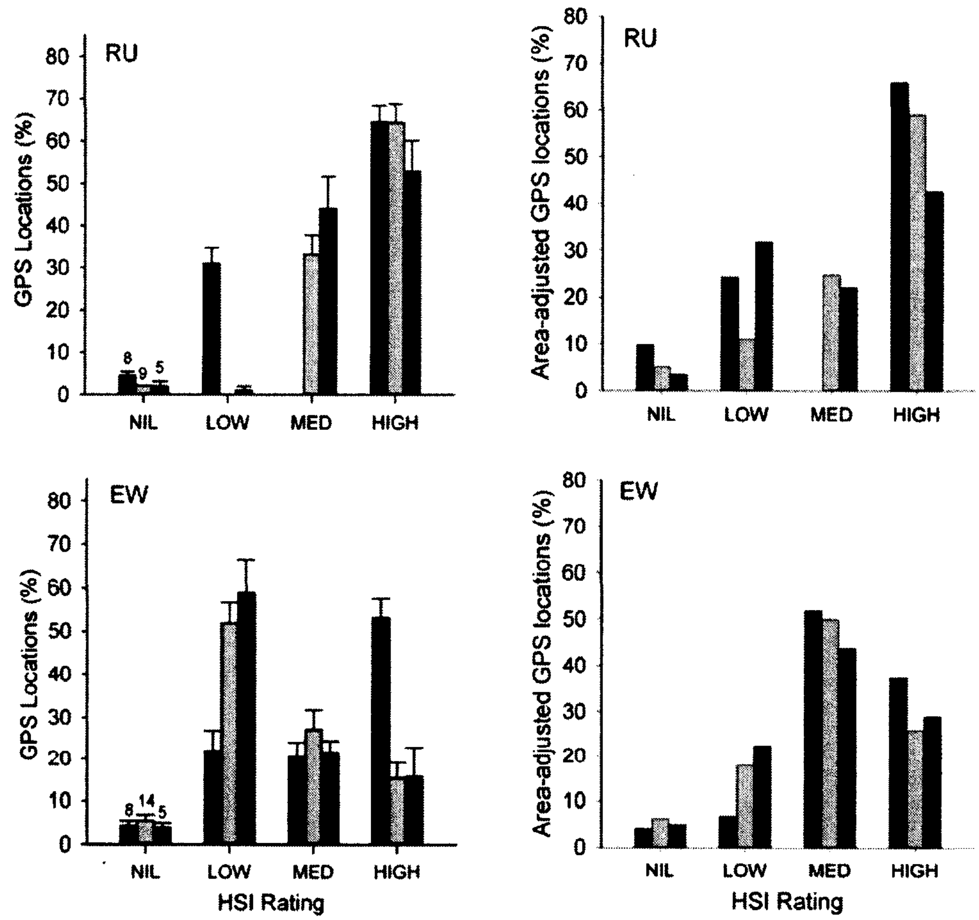


Figure 4.4. Continued.

riparian zones surrounding small streams at higher elevations. These areas are often higher in preferred willow species rather than dwarf birch, which often dominated higher elevations. The locations of female moose with calves were also most often in areas of medium suitability during Early Winter. Medium suitability for females with calves was identified from local knowledge as Lowland Shrub, whereas high suitability was identified as Upland Shrub. Therefore, it appears that females with calves used lower elevations than predicted for Early Winter. This corroborates well with the elevation data (Chapter 2), showing that females with calves used lower elevations in October than females without calves.

In general, female moose with calves were more variable in their response to habitat suitability as defined by local knowledge. During Late Winter, females with calves were more frequently in areas classed as low suitability (i.e., Deciduous and Conifer classes) than in areas classed as high suitability (i.e., Riparian, Wetland, Mixed Wood, Lowland Shrub). As such, females with calves may have selected cover at the expense of forage accessibility in Late Winter when snow was deepest. Conifer stands provide concealment cover from predators and lower snow depths, both of which help enable calf survival at an energetically-costly time of the year (Mysterud and Ostbye 1999, White and Berger 2001). Females with calves appeared to use the opposite strategy during Rut, when low suitability (i.e., Deciduous, Lowland Herb) was similarly favoured over areas of medium suitability (i.e., Mixed Wood, Conifer). In this season, females with calves used areas of greater forage value than cover, at a time of the year when forage may have still been growing and snow was negligible.

In the Summer season, both female groups used land-cover classes of low suitability (i.e., with calf: Deciduous, Conifer, Lowland Herb; without calf: Deciduous, Mixed Wood, Conifer, Lowland Shrub, Lowland Herb) more than medium suitability (i.e., Upland Shrub). The use of these land-cover classes suggests that female moose were generally at lower elevations than predicted by local knowledge. Again, the use data support these findings (Chapter 2: Fig. 2.2); females used more Lowland Shrub than Upland Shrub and were found at significantly lower elevations than males during Summer (specifically July and August).

That GPS locations did not always follow the patterns predicted by local knowledge was perhaps more of a limitation of the HSI methodology than of the local knowledge base. The number of participants was low (n = 18), but more importantly, the context of ecological relationships made it difficult for participants to rank habitat value based only on land-cover classes. Many participants prefaced their habitat rankings with "it depends on" and "sometimes if". Additionally, the GPS locations for moose spanned a relatively limited time frame (i.e., 2 years) compared to several years or decades of local knowledge. Radio-collared animals may have responded to short-term variation in climatic conditions or other factors not accounted for by local knowledge. The locations of male moose more closely followed the distribution predicted by local knowledge-based habitat suitability than the other groups, possibly because local knowledge of moose is often gained during harvesting activities when male moose are usually the target.

Knowledge-based habitat suitability indices can provide a cost-effective method for gathering information on moose and their habitats, while strengthening ties to local communities. More efforts, however, should be focused on finding methods that capture local and traditional knowledge of a wider breadth of ecological variables affecting moose than land-cover classes alone, as well as the effects of interacting variables.

Post-Rut Aerial Location Data

Also concurrent with the South Canol moose telemetry study, 3 RSFs (Cow Calf, Group Moose, Single Moose) were developed by Yukon Department of Environment for a core portion of the study area using early winter aerial census data collected over 14 years (1994–2007). These RSFs incorporated slope and landform, aspect, and elevation (Clarke 2013). Extensive moose census data exist for many parts of Yukon and are potentially an inexpensive and less invasive alternative to radio-collaring animals for defining winter habitat selection.

I examined the distribution of GPS telemetry locations from Early Winter in my study relative to the aerial-census RSF values developed by Yukon Department of Environment to determine if detailed observations of the radio-collared moose over the Early Winter conformed to models based on the brief aerial surveys. The numerous GPS-use points collected from collared moose were used to validate RSF models. Only females with calves were compared to the Cow Calf RSF. Both males and females without calves were queried with both the Group Moose and Single Moose RSFs. I divided the RSF values into 10 bins based on equal area (Fig. 4.5). If the Early Winter RSFs also described resource selection of radio-collared moose, then most GPS locations should be associated with higher RSF values. For each RSF, most locations were always in the top 10% of area-adjusted RSF values. Cows with calves had the most variable distribution because of small sample size. GPS locations relative to the Single and Group Moose RSFs were distributed in a more predictable manner, with the exception of bin 2 for Group Moose. This bin had nearly as many locations as the top bin and may have been an artefact of the skewed distribution of RSF values over the total census area.

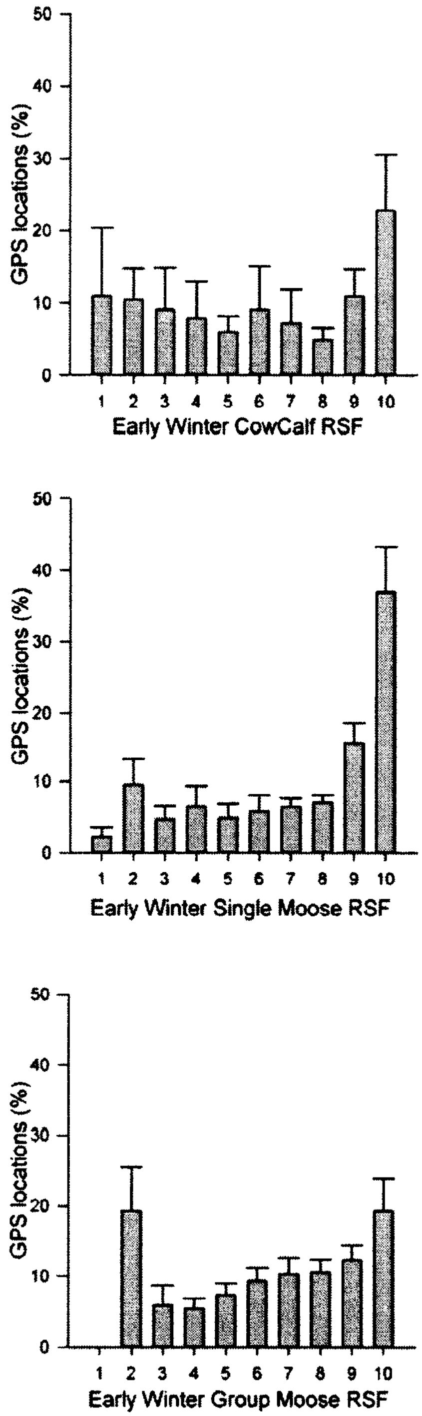


Figure 4.5. Percent ($\bar{x}$ ± SE) of GPS locations of radio-collared moose in each of 10 area-adjusted bins making up the Early Winter RSFs (resource selection functions) based on post-rut aerial surveys of cow-calf pairs, single moose, and group moose in the South Canol area of south-central Yukon. RSFs were developed by Clarke (2013).

Differences in sample size, data collection, and variables within selection models made it difficult to interpret the RSF values assigned to GPS locations. Despite these limitations, post-rut aerial survey data seem to be suitable for identifying the highest-value Early Winter habitat, as indicated by the greatest number of moose locations often being in the top 10% of RSF values. In the absence of other data, this information could be used by resource managers to identify high-value early winter habitats to ensure that future development or disturbance of these areas is minimized at a time of the year when moose are recovering from the breeding season. Information from these surveys, however, may not be applicable to use and selection in other seasons.

STUDY LIMITATIONS AND FUTURE RESEARCH

GPS Telemetry Locations

GPS radio-collars enable frequent sampling of detailed location data for highly mobile species such as moose. These location data have limitations, however, including biased fix rates, spatial autocorrelation, and measurement error (Frair *et al.* 2004, 2010).

In my study, fix rates obtained from one brand of radio-collars (HRI) were much lower than the other (Lotek). This limited my analyses to some extent because I had to ensure that results were not biased toward particular individuals with more location fixes. Lower fix rates also resulted from deletion of a greater number of improbable locations. I was unable to filter locations by dilution of precision (DOP) values or by selecting only 3-D fixes, values which were not provided by the HRI collars. This limitation made careful examination of location data using Spatial Viewer (M. Gillingham, Visual Basic program) a critical part of data preparation, and errant location points were deleted manually.

Autocorrelation refers to temporal and/or spatial correlation among locations, and is inherent in large, frequently-sampled GPS-telemetry datasets (Cagnacci *et al.* 2010). Autocorrelation violates statistical assumptions that call for independent sampling and can impact inferences from habitat-selection models (Nielsen *et al.* 2002). In this study, however, the effects of autocorrelation were minimized through high collar fix rates, collection of locations over an ecologically meaningful study period (i.e., seasonally over 2 years), and by assigning individual moose as the sample unit rather than individual location points.

During the course of my study, one moose died in Upland Shrub with a fully-functioning Lotek collar, providing an opportunity to assess GPS-collar field accuracy in this land-cover class. The collar continued to collect fixes for 325 days. During this time the mean distance between fixes was 7.9 ± 0.25 m. Given the resolution of available land-cover data, the land-cover classes associated with the GPS locations in my study are fairly accurate.

Land-cover Classification

Land-cover classifications based on satellite imagery are an efficient and cost-effective means of obtaining cover information over large areas. The South Canol study area spanned a remote and isolated area larger than Belgium. An existing Earth Observation for Sustainable Development (EOSD) classification was available for the entire Yukon, had a species-appropriate resolution (25 m), and was based on digital imagery collected within 8 years of the study (i.e., Landsat 7, 2000). This EOSD classification, however, did have some error associated with the classification process. EOSD imagery consisted of 5 levels of classification. Each level provided greater detail than the level above, but also had greater probability of error (Wulder *et al.* 2003). I reduced the chances for error by combining some of the 24 land-cover classes into 8 classes relevant to moose biology (Fig. 4.1, Appendix A).

Logistical issues prevented successful ground-truthing of the classification, but the 8 land-cover classes likely had at least 75–80% accuracy (M. Waterreus, Yukon Department of Environment, *pers. comm.*).

The EOSD classification used in my study is now 14 years old at the time of writing. During this time, changes in land cover could have resulted from changes in the age structure of vegetation associated with forest succession, although the relatively low productivity of the area and very few new wildfires would suggest these changes are not substantial. With a warming climate and associated increases in wildfires, as well as proposed anthropogenic alterations, subsequent studies in the South Canol area should consider updating the land-cover data layer with new imagery.

Selection Models

I incorporated land cover, topography, predation risk, and harvest vulnerability (Rut season only) in the moose selection models. The variable that was the least location-specific was predation risk. The predation-risk surfaces were created using RSF models built from data gathered in northern British Columbia. To assess how appropriate this might be in lieu of predator information for the South Canol area, the risk surfaces (Fig. 4.2) were presented to the local community in Teslin. The maps of seasonal risk patterns were believed to be reasonably representative of local wolf and bear behaviour. Because many moose populations are predator-controlled in Yukon, however, there should be high priority placed on gathering data for local predator populations. The number of moose kills has been shown to be influenced by the density and size of resident wolf packs (Hayes *et al.* 2000a). Data on wolf density and pack locations, therefore, would confirm or update the existing risk surfaces.

Because hunting is an important component of the South Canol moose system, I also created a harvest vulnerability layer (Fig. 4.3) for selection models in Rut (males only). This layer was based on the proportion of documented moose that was harvested in a particular land-cover class and distance to access (>500 or <500 m from roads or waterways). Although vulnerability can be difficult to quantify, I assumed that areas with the greatest proportion of moose harvests indicated areas where moose were most vulnerable. The interviews were voluntary and represented a small portion of total kills in the area. Additionally, some kills occurred up to 5 years prior; therefore, memory of older kills may not have been as accurate as more recent kills. Sixty-three hunters were interviewed and 99 kills were documented in 13 cover-access combinations, with over 80% occurring in Riparian, Wetland, or Water. Despite the limitations of data collection, major rivers and lakes, and the South Canol Road are the primary means that hunters have used successfully to access moose in the South Canol area and future harvest management should focus on the game management subzones bordering these areas.

The Late Winter selection models developed for my study may be associated with the least certainty. With only a few individuals included in the final Late Winter models, there could have been additional factors influencing Late Winter habitat selection by moose in the South Canol area. Late Winter is a critical time of the year, with few options for survival. Collecting additional data on Late Winter habitat use and selection would be useful, particularly if the effects of climate change and/or land-based development become more prominent. Model inference is strongest for Calving models, which were represented by the greatest number of individuals (i.e., largest effective sample size). Individual Calving models were also the most variable, indicating that moose were less constrained compared to other seasons.

MANAGEMENT RECOMMENDATIONS

Landscape alterations associated with land-development activities have the greatest potential to impact moose behaviour and movements in south-central Yukon. The direct effects of disturbance usually result in alteration of the physical environment (Trombulak and Frissell 2000). Moose habitats may be improved through increased browse production and increased edge effects (Courtois and Beaumont 1999, Schneider and Wasel 2000). Conversely, habitat loss and fragmentation may occur (Crichton *et al.* 2004, Forman and Alexander 1998, Westworth *et al.* 1989). Increased access can increase hunting pressure and moose vulnerability (Thiel 1984, McLellan and Shackleton 1988, Mech *et al.* 1988, Courtois and Beaumont 1999, James and Stuart-Smith 2000, Trombulak and Frissell 2000, Crichton *et al.* 2004,). The indirect effects of disturbance can alter behaviour, home-range size, movement patterns, physiological states, reproductive success, escape responses, and predator-prey dynamics. Increased access to wilderness areas increases contact between humans and moose. Moose living close to communities and areas of industrial development could benefit from increased forage production, decreased predation risk, and restrictive hunting regulations (Schneider and Wasel 2000, Westworth *et al.* 1989). Conversely, moose less tolerant of human presence may be displaced into less-preferred habitats with reduced forage and higher risk (Crichton *et al.* 2004, Westworth *et al.* 1989). With higher risk, increased vigilance may result in inefficient foraging patterns and increased energy costs (Boyle and Samson 1985, Colescott and Gillingham 1998). Such effects tend to be most pronounced in winter because of poor body condition, limited forage, and snow conditions

(Andersen *et al.* 1996). Additionally, disturbance effects may be cumulative and may radiate substantial distances from the disturbances (James and Stuart-Smith 2000, Trombulak and Frissell 2000).

My study provided an opportunity to identify the key attributes used and selected by male and female moose in south-central Yukon, and it provides valuable baseline data for moose management and relative to future landscapes. In the South Canol area, managed landscapes will need to accommodate potentially large ranges, as evidenced by male telemetered moose. Moose must also have a variety of elevational gradients available throughout the year. Lower elevations may be a critical part of winter range in areas that receive high snowfall. The importance of land-cover classes varied seasonally; however, high selection for Upland and Lowland Shrub and Riparian classes in all seasons by both male and female moose indicates the importance of access to an adequate forage base throughout the year. The distribution and quantity of shrub-dominated land cover can provide a rough indication of the available forage base on the landscape.

At the resolution of this study, seasonal changes had a far greater effect on habitat use and selection by moose than did reproductive status. Gender differences would likely be more prominent at finer scales than documented in my study, whereas climatic factors influenced both sexes similarly. Based on these findings, resource managers can manage both sexes of moose with the same prescriptions at the seasonal scale, recognizing that there is individual variation.

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Appendix A: Land-cover classes relevant to moose, created from an EOSD land cover classification and topographic data available for the South Canol study area in south-central Yukon.

EOSD cover class[1]	Data Layer[2]	Land-cover Class
Coniferous Dense Coniferous Open Coniferous Sparse Pine Dense Pine Open Pine Sparse		Conifer
Mixed Wood Dense Mixed Wood Open Mixed Wood Sparse		Mixed Wood
Wetland Treed Wetland Shrub	NTDB	Riparian
Shrub Tall Shrub Low Broadleaf Dense Broadleaf Open Broadleaf Sparse	DEM	Lowland Shrub (<1300 m elevation) Upland Shrub (>1300 m elevation)
Herbs Bryoids *Snow/Ice*** *Rock/Rubble*** *Exposed Land*** *No Data ***	DEM	Lowland Open (<1300 m elevation) Alpine (>1300 m elevation)
Water		Water

***Alpine class only*

[1] EOSD = Earth Observation for Sustainable Development of Forests

[2]NTDB = National Topographic Database; DEM = digital elevation model

Appendix B: Percent (%) use of 8 land-cover classes by individual radio-collared moose in the South Canol study area of south-central Yukon. Seasonal use is based on telemetry locations and annual statistics are availability based on 100% minimum convex polygon (MCP) annual ranges. The landscape summary is availability based on a 100% MCP range for all used and available locations (see Chapter 2). Values are rounded up to the nearest percentage.

		Land-cover Class							
Animal ID	**Season**	**Conifer**	**Lowland Shrub**	**Upland Shrub**	**Alpine**	**Riparian**	**Mixed Wood**	**Lowland Open**	**Water**
Landscape		45	12	12	14	7	5	2	1
Female Moose:									
137	Late Winter	15	65	3	0	11	5	0	2
	Calving	9	11	0	0	75	3	0	3
	Summer	8	33	0	0	58	0	0	0
	Rut	.	.	.	.	.	.	.	.
	Early Winter	.	.	.	.	.	.	.	.
	ANNUAL	.	.	.	.	.	.	.	.
138	Late Winter	30	41	0	0	18	9	2	0
	Calving	34	29	13	2	4	17	0	0
	Summer	28	40	3	0	18	10	1	1
	Rut	22	44	18	3	7	5	1	0
	Early Winter	28	37	10	2	8	11	3	0
	ANNUAL	47	22	9	2	7	12	1	0
143	Late Winter	33	17	0	0	42	5	1	2
	Calving	52	28	0	0	14	1	1	4

		Land-cover Class							
Animal ID	**Season**	**Conifer**	**Lowland Shrub**	**Upland Shrub**	**Alpine**	**Riparian**	**Mixed Wood**	**Lowland Open**	**Water**
	Summer	65	11	0	0	10	12	0	3
	Rut	48	21	0	0	14	14	1	2
	Early Winter	73	18	0	1	7	1	0	0
	ANNUAL	.	.	.	.	.	.	.	.
144	Late Winter	51	30	0	0	15	4	0	0
	Calving	25	55	0	0	15	5	0	0
	Summer	50	50	0	0	0	0	0	0
	Rut	36	13	29	1	11	9	0	0
	Early Winter	21	21	16	1	31	4	4	4
	ANNUAL	58	10	6	10	6	6	0	2
145	Late Winter	70	9	0	0	17	4	0	0
	Calving	57	8	0	0	26	7	1	1
	Summer	16	19	47	2	7	2	1	6
	Rut	21	1	64	6	6	1	0	0
	Early Winter	31	20	42	1	3	2	2	0
	ANNUAL	66	8	7	5	7	3	1	3
147	Late Winter	66	14	0	0	14	4	0	1
	Calving	54	36	0	0	5	4	0	1
	Summer	74	12	0	0	5	8	0	2

		Land-cover Class							
Animal ID	Season	Conifer	Lowland Shrub	Upland Shrub	Alpine	Riparian	Mixed Wood	Lowland Open	Water
	Rut	54	21	8	1	9	4	1	3
	Early Winter	18	31	17	1	25	3	2	3
	ANNUAL	.	.	.	.	.	.	.	.
148	Late Winter	55	6	0	0	29	6	1	3
	Calving	72	3	0	0	16	2	0	7
	Summer	55	12	0	0	23	5	0	5
	Rut	22	19	26	4	23	2	0	4
	Early Winter	23	16	22	5	26	2	1	4
	ANNUAL	63	16	2	2	9	6	1	2
149	Late Winter	78	14	0	0	2	5	0	0
	Calving	38	40	0	0	6	13	3	0
	Summer	49	21	0	0	16	10	3	0
	Rut	48	30	1	0	5	9	5	2
	Early Winter	49	29	2	0	9	8	3	1
	ANNUAL	60	18	3	2	6	6	3	2
152	Late Winter	45	48	0	0	1	6	0	0
	Calving	27	40	11	1	9	10	2	1
	Summer	44	19	0	0	23	5	4	4
	Rut	42	25	8	2	9	9	3	2

Animal ID	Season	Land-cover Class Conifer	Lowland Shrub	Upland Shrub	Alpine	Riparian	Mixed Wood	Lowland Open	Water
	Early Winter	28	8	43	6	11	4	1	0
	ANNUAL	57	18	2	1	9	6	5	2
153	Late Winter	53	22	0	0	18	4	1	2
	Calving	38	14	0	0	35	4	2	7
	Summer	59	11	0	0	23	5	0	1
	Rut	48	12	1	0	26	7	1	5
	Early Winter	46	33	0	0	11	9	1	0
	ANNUAL	60	18	3	1	9	7	1	1
154	Late Winter	52	36	0	0	3	9	0	0
	Calving	19	17	17	12	30	2	0	2
	Summer	8	8	17	0	58	0	0	8
	Rut	23	9	39	2	27	0	0	0
	Early Winter	14	59	17	6	0	3	1	0
	ANNUAL	.	.	.	.	.	.	.	.
155	Late Winter	37	28	0	0	28	4	1	1
	Calving	27	33	0	0	30	10	0	0
	Summer	36	12	0	0	44	7	0	2
	Rut	36	11	19	1	29	4	0	1
	Early Winter	31	22	6	0	29	5	5	2

Animal ID	Season	Land-cover Class Conifer	Lowland Shrub	Upland Shrub	Alpine	Riparian	Mixed Wood	Lowland Open	Water
	ANNUAL	50	11	10	13	8	6	1	1
157	Late Winter	53	26	0	0	6	14	0	0
	Calving	42	32	1	0	12	10	1	1
	Summer	51	26	0	0	13	7	0	2
	Rut	37	32	10	2	9	7	1	2
	Early Winter	35	33	14	1	10	8	0	0
	ANNUAL	48	23	5	4	8	8	1	1
158	Late Winter	13	6	61	7	6	7	0	0
	Calving	5	0	74	8	11	1	0	0
	Summer	24	8	43	4	15	3	1	2
	Rut	9	2	60	20	7	3	0	0
	Early Winter	2	7	55	19	16	1	0	0
	ANNUAL	.	.	.	.	.	.	.	.
160	Late Winter	28	37	16	0	11	8	0	0
	Calving	35	40	1	2	9	13	0	0
	Summer	27	7	50	1	6	8	0	0
	Rut	14	25	37	5	12	5	0	0
	Early Winter	9	27	34	3	24	3	0	0
	ANNUAL	31	14	19	22	5	7	1	0

Animal ID	Season	Land-cover Class Conifer	Lowland Shrub	Upland Shrub	Alpine	Riparian	Mixed Wood	Lowland Open	Water
161	Late Winter	33	46	0	0	10	10	0	0
	Calving	40	29	12	2	6	10	0	0
	Summer	46	24	18	1	2	9	0	0
	Rut	21	32	31	4	5	7	0	0
	Early Winter	19	51	3	1	19	7	1	0
	ANNUAL	35	16	13	21	6	9	1	0
Male Moose:									
136	Late Winter	25	55	1	0	7	11	0	0
	Calving	25	59	1	0	7	8	0	0
	Summer	33	26	6	0	16	10	1	10
	Rut	16	15	42	6	11	9	1	1
	Early Winter	7	37	22	2	27	4	0	0
	ANNUAL	57	15	4	3	8	10	1	2
140	Late Winter	28	33	3	0	27	8	3	0
	Calving	38	20	8	0	17	7	10	1
	Summer	33	6	46	2	3	8	0	0
	Rut	31	5	45	2	10	6	0	0
	Early Winter	16	19	38	3	15	5	1	3

Animal ID	Season	Land-cover Class Conifer	Lowland Shrub	Upland Shrub	Alpine	Riparian	Mixed Wood	Lowland Open	Water
141	ANNUAL	41	21	16	6	6	9	1	0
	Late Winter	60	21	0	0	11	6	1	1
	Calving	41	15	12	0	25	4	1	1
	Summer	44	4	28	3	18	1	1	1
	Rut	37	10	23	5	21	2	1	2
	Early Winter	26	20	13	0	33	4	1	2
146	ANNUAL	58	12	7	6	8	6	2	1
	Late Winter	41	27	6	0	19	4	3	0
	Calving	22	37	11	1	9	7	13	0
	Summer	39	28	0	0	20	6	4	3
	Rut	40	25	6	1	14	4	9	1
	Early Winter	16	8	48	6	19	2	2	0
150	ANNUAL	32	8	19	28	6	3	1	0
	Late Winter	32	11	0	0	46	8	1	2
	Calving	23	25	10	1	30	8	1	2
	Summer	33	17	26	5	12	7	1	1
	Rut	28	19	24	4	15	9	1	0
	Early Winter	12	24	33	1	27	2	1	0

		Land-cover Class							
Animal ID	**Season**	**Conifer**	**Lowland Shrub**	**Upland Shrub**	**Alpine**	**Riparian**	**Mixed Wood**	**Lowland Open**	**Water**
	ANNUAL	43	9	18	13	7	8	1	0
151	Late Winter	41	51	0	0	0	8	0	0
	Calving	49	28	2	0	9	10	0	1
	Summer	41	9	26	5	7	9	2	0
	Rut	35	7	34	8	8	6	1	1
	Early Winter	43	44	0	0	7	5	0	1
	ANNUAL	65	11	5	2	4	9	0	2
159	Late Winter	1	10	62	9	17	1	0	0
	Calving	18	36	26	4	9	6	1	0
	Summer	6	6	77	5	4	2	0	0
	Rut	13	15	57	3	7	6	0	0
	Early Winter	3	5	69	10	13	1	0	0
	ANNUAL	18	7	34	31	5	4	0	0
162	Late Winter	39	23	13	0	9	15	1	0
	Calving	36	29	1	0	24	9	1	0
	Summer	37	19	23	1	7	13	0	0
	Rut	30	9	45	3	7	6	0	0
	Early Winter	12	17	45	2	18	6	0	0

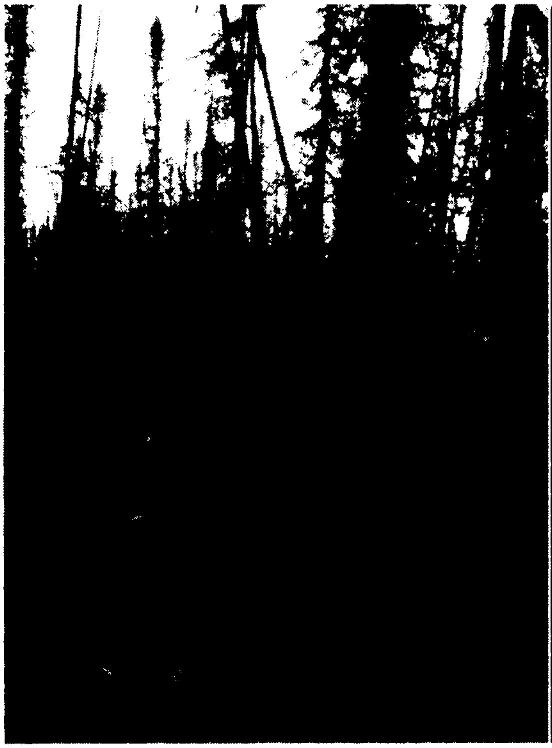
		Land-cover Class							
Animal ID	**Season**	**Conifer**	**Lowland Shrub**	**Upland Shrub**	**Alpine**	**Riparian**	**Mixed Wood**	**Lowland Open**	**Water**
	ANNUAL	45	17	11	7	9	9	1	1

Appendix C. Spearman's chi-squared test statistics indicating differences between percent of 8 land-cover classes available on the landscape (represented by a 100% minimum convex polygon (MCP) around all buffered used and available points within the South Canol study area) and available within individual annual home ranges (100% MCP around all used points) of radio-collared moose in the South Canol study area of south-central Yukon.

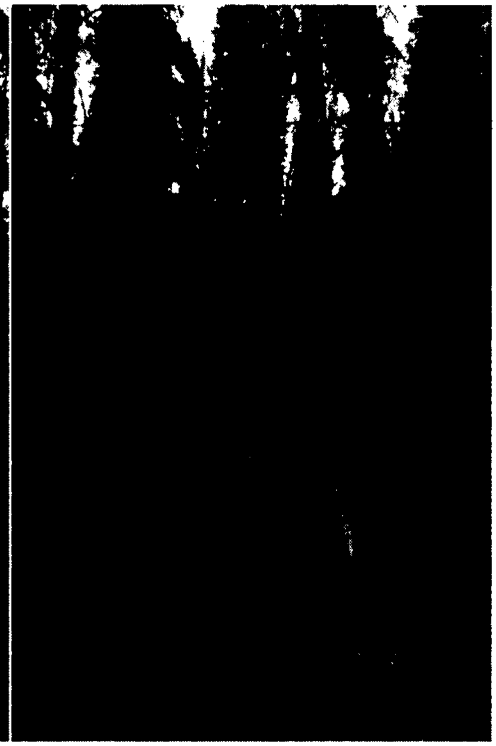
Animal	χ^2	df	*P*
Male moose:			
136	460.47	8	<0.001
140	434.40	8	<0.001
141	449.38	8	<0.001
146	430.01	8	<0.001
150	430.28	8	<0.001
151	477.59	8	<0.001
159	452.79	8	<0.001
162	432.74	8	<0.001
Female Moose:			
138	453.18	8	<0.001
144	453.25	8	<0.001
145	470.23	8	<0.001
147	481.56	8	<0.001
148	466.58	8	<0.001
149	470.31	8	<0.001
152	466.32	8	<0.001
153	479.56	8	<0.001
155	434.34	8	<0.001
157	447.07	8	<0.001
160	427.04	8	<0.001
161	424.66	8	<0.001

Appendix D. Representative photographs used to define14 land-cover classes during interviews conducted by Yukon Department of Environment to collect local and traditional knowledge. Photos provided by Yukon Department of Environment.

SPRUCE-FIR CLASS

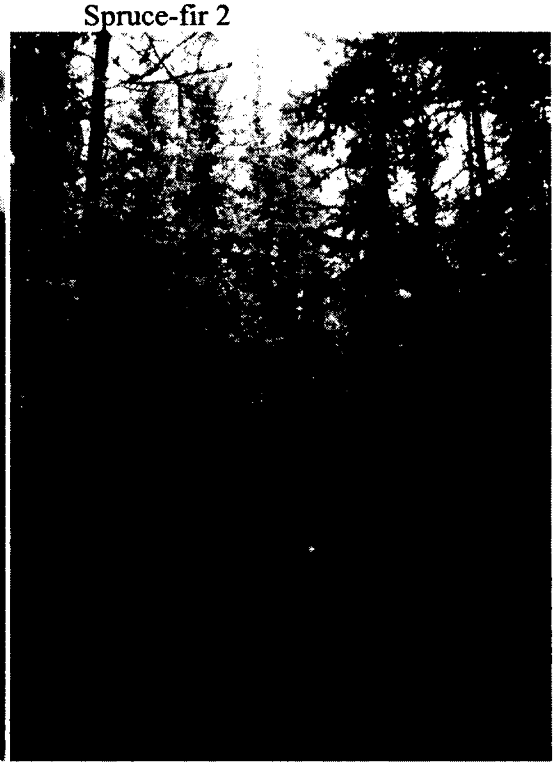


Spruce-fir 1

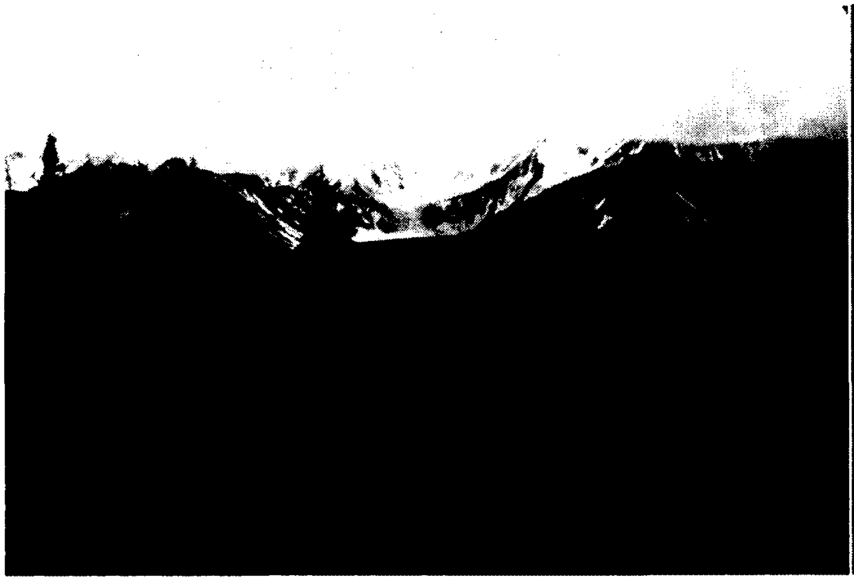


Spruce-fir 2

Spruce-fir 3

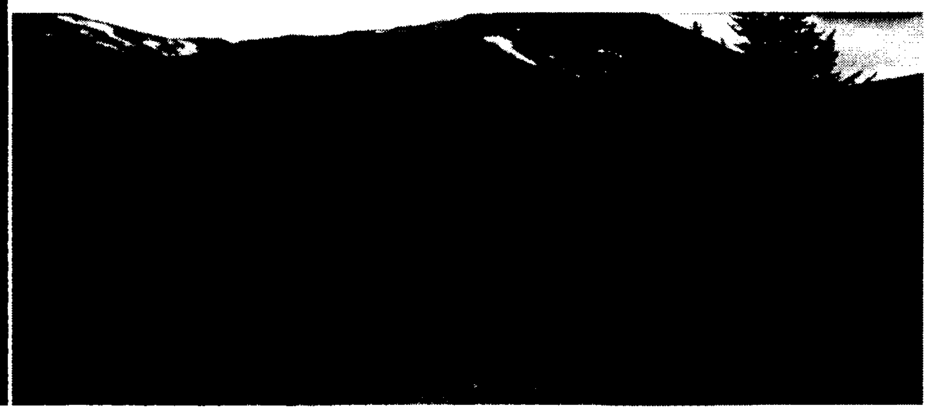


Spruce-fir 4


Spruce-fir 5

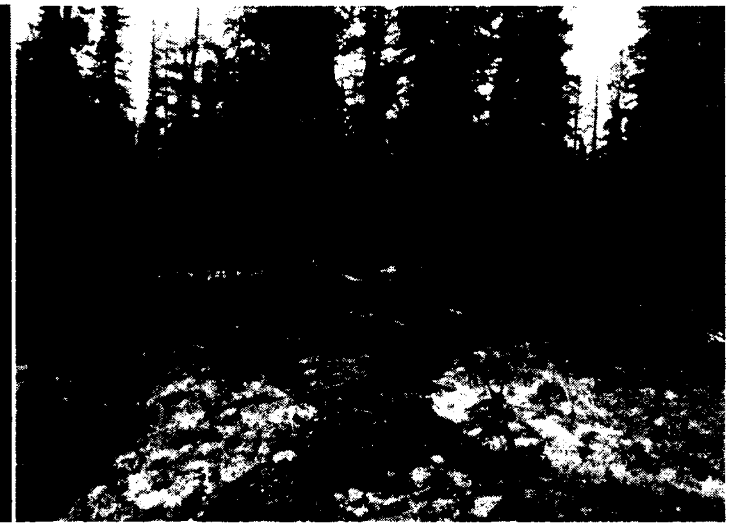

Spruce-fir 6


Spruce-fir 7


Spruce-fir 8

PINE CLASS


Pine 1

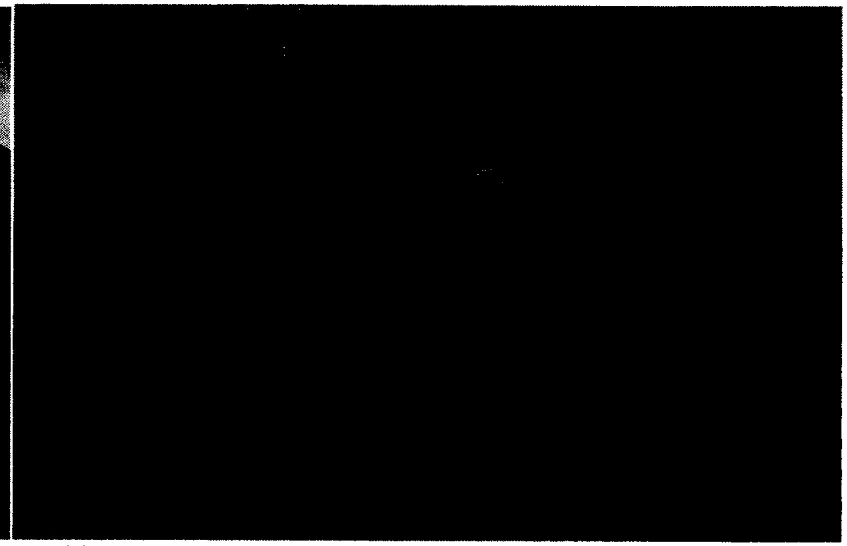

Pine 2

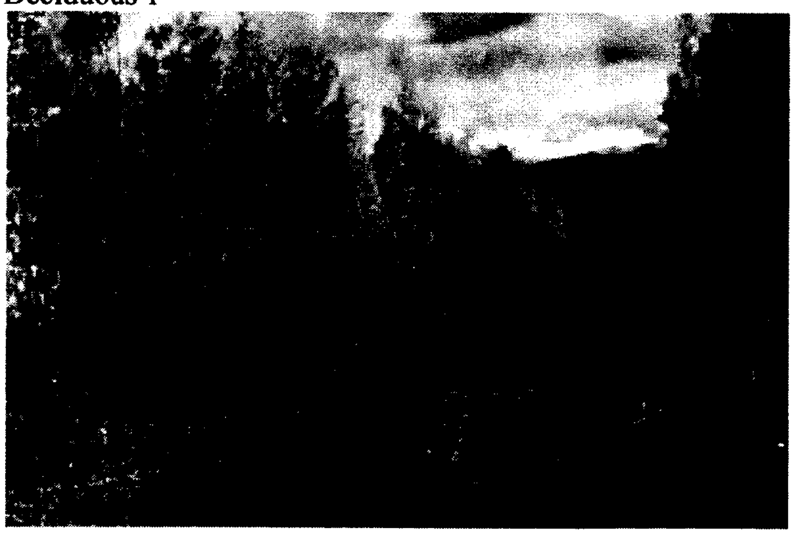

Pine 3


Pine 4

DECIDUOUS CLASS


Deciduous 1

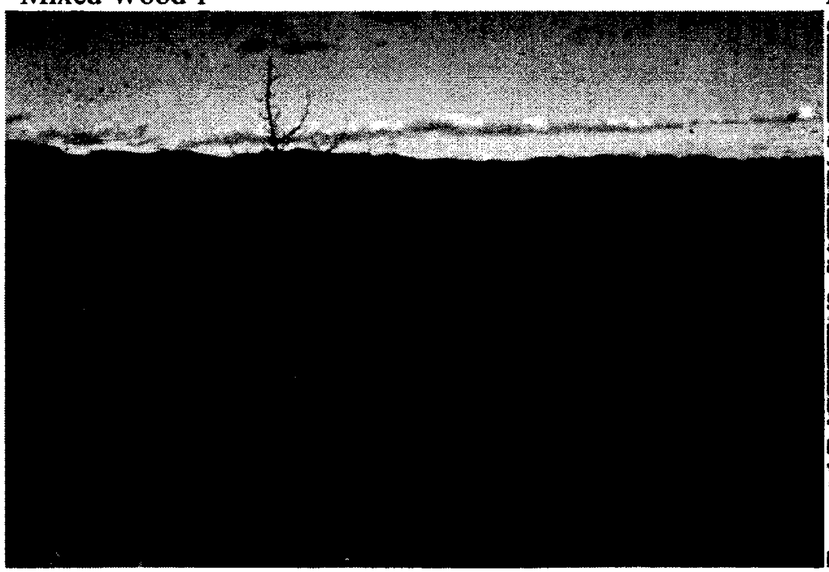

Deciduous 2


Deciduous 3

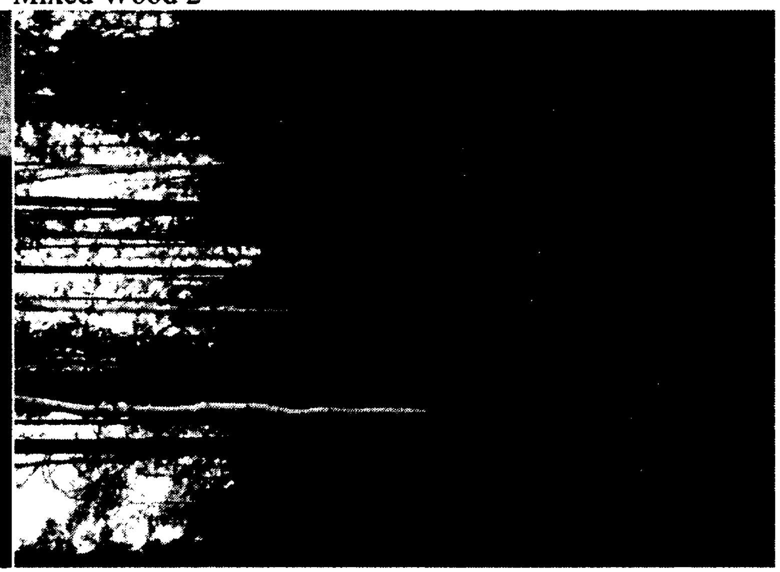
MIXED WOOD CLASS

Mixed Wood 1

Mixed Wood 2



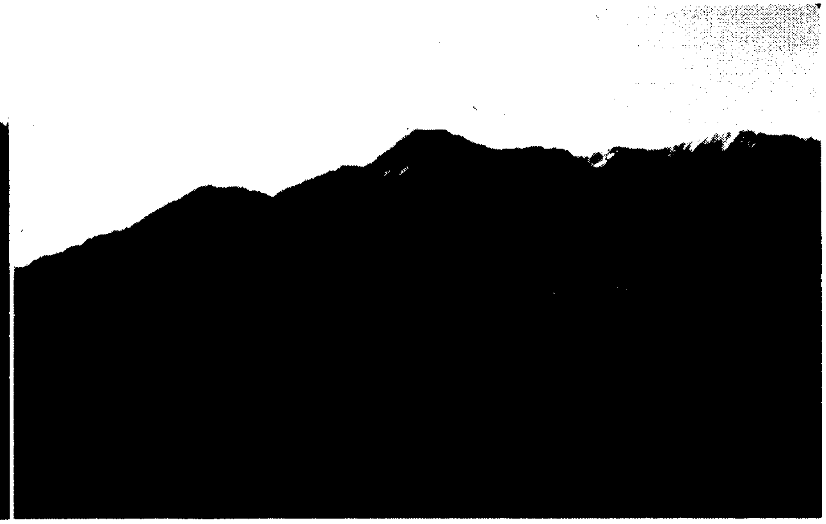
Mixed Wood 3



Mixed Wood 4

LOWLAND SHRUB CLASS

Lowland Shrub 1



Lowland Shrub 2

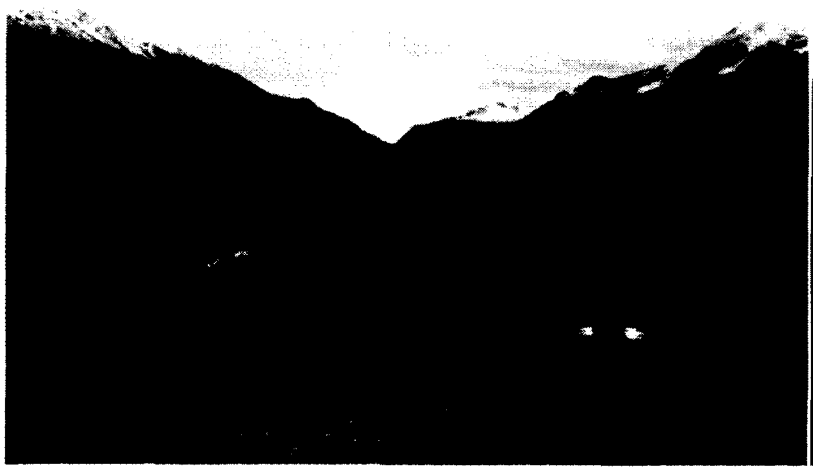
Lowland Shrub 3

Lowland Shrub 4

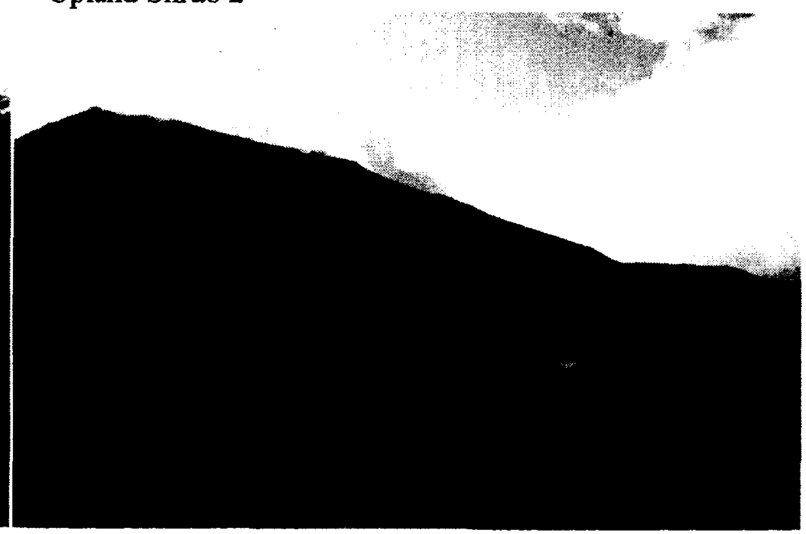
UPLAND SHRUB CLASS

Upland Shrub 1

Upland Shrub 2

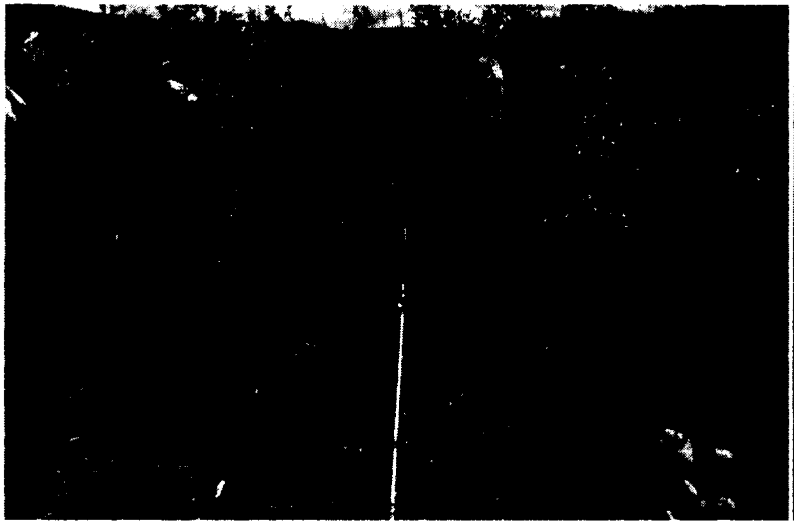


Upland Shrub 3



Upland Shrub 4

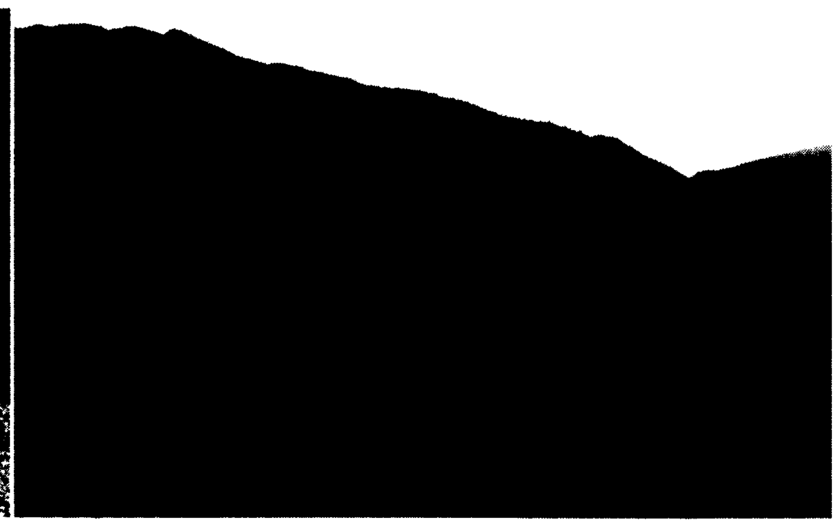
BURN SHRUB CLASS



Burn Shrub 1

Burn Shrub 2

Burn Shrub 3



Burn Shrub 4

ALPINE CLASS

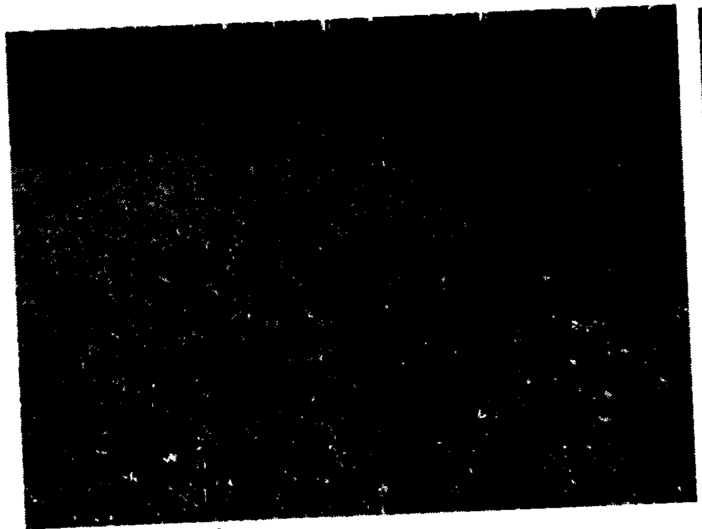
Alpine 1

Alpine 2

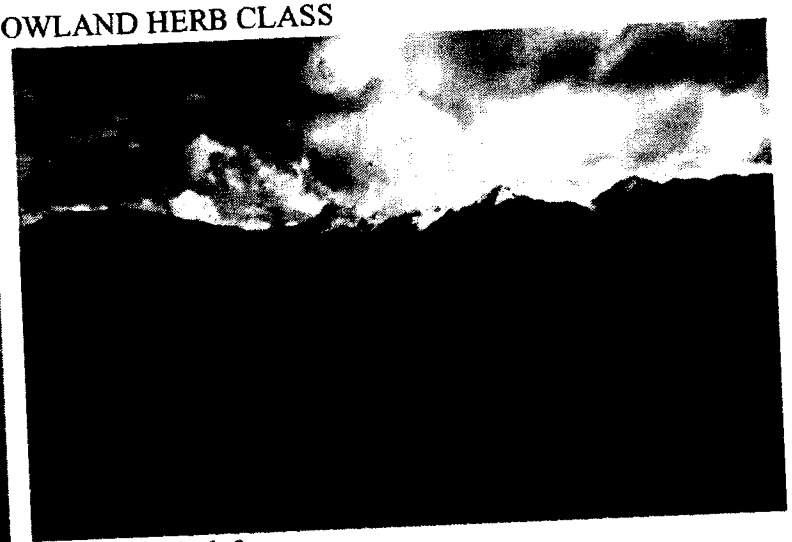
Alpine 3

Alpine 4

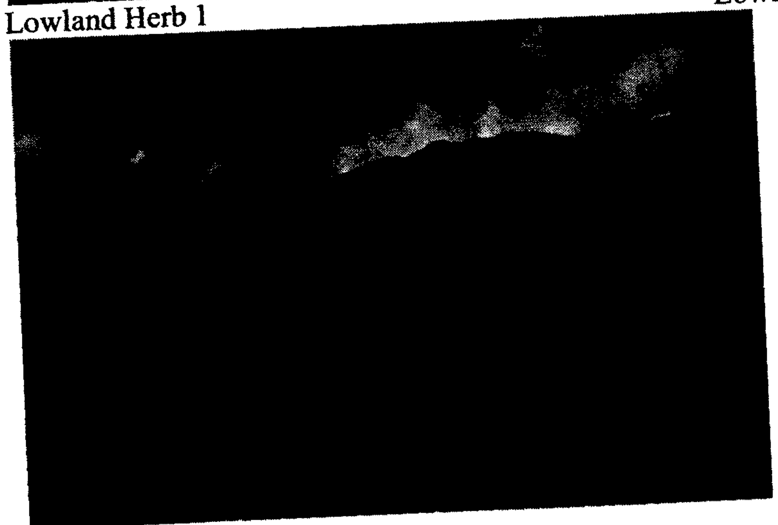
LOWLAND HERB CLASS



Lowland Herb 1

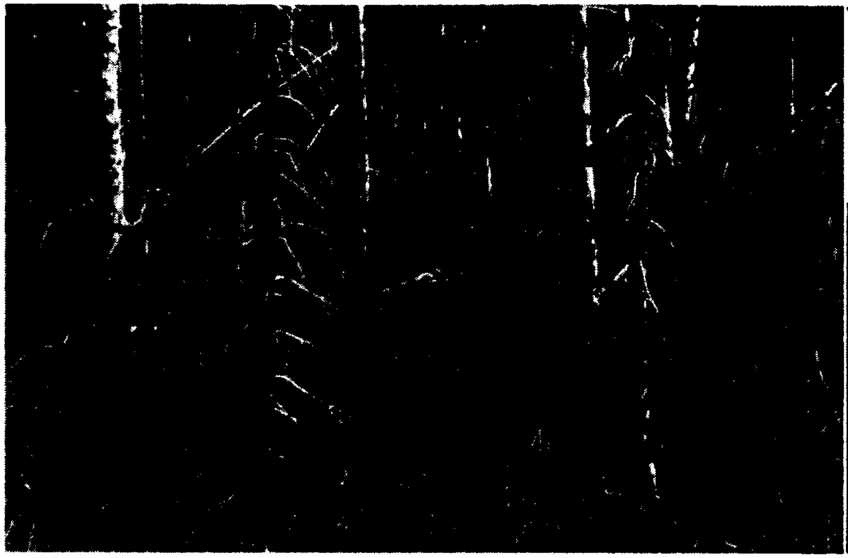


Lowland Herb 2



Lowland Herb 3

BURN HERB CLASS



Burn Herb 1

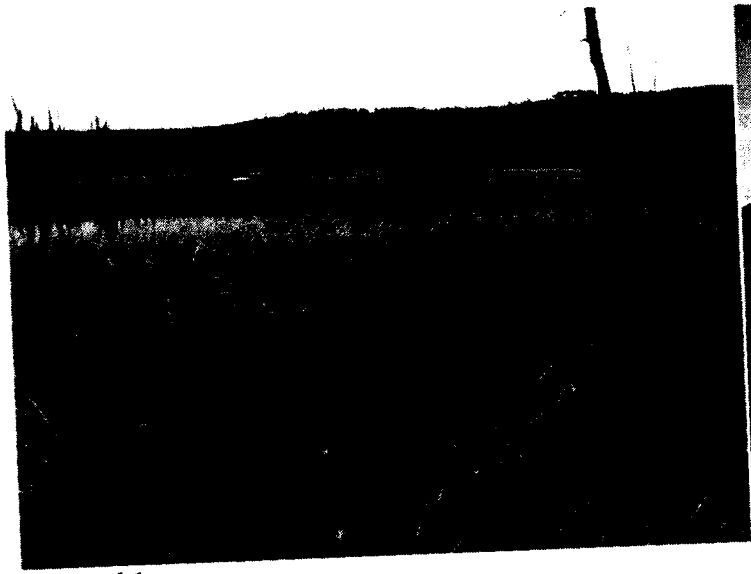
Burn Herb 2

NON-VEGETATED CLASS

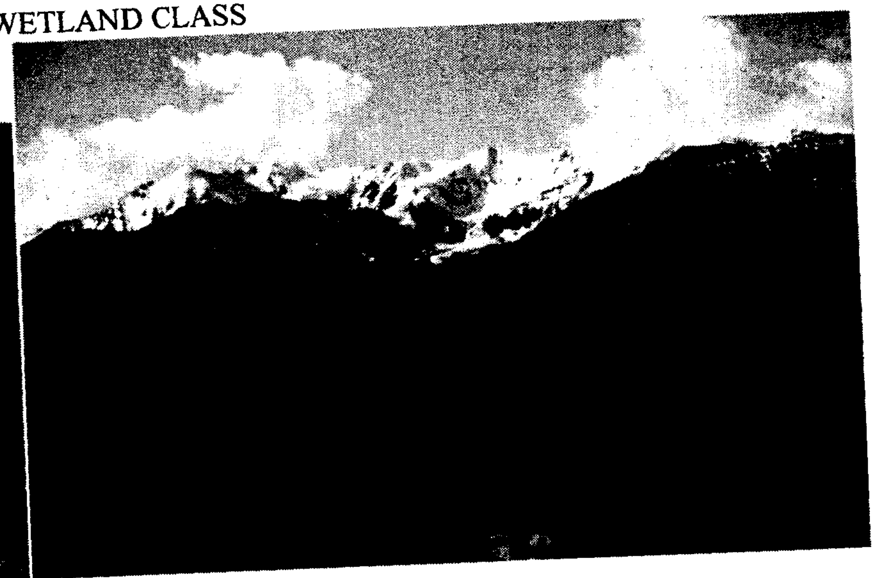
Non-vegetated1

Non-vegetated 2

WETLAND CLASS



Wetland 1



Wetland 2

Wetland 3

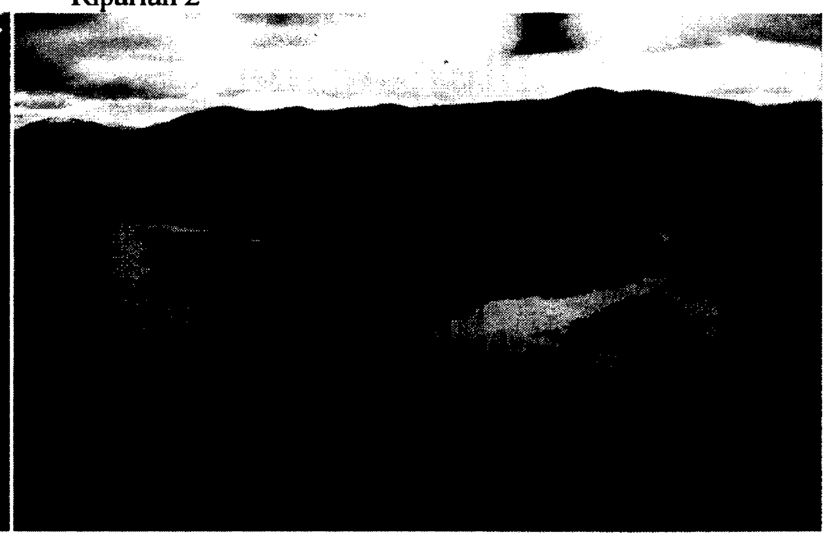
Wetland 4

RIPARIAN CLASS

Riparian 1

Riparian 2

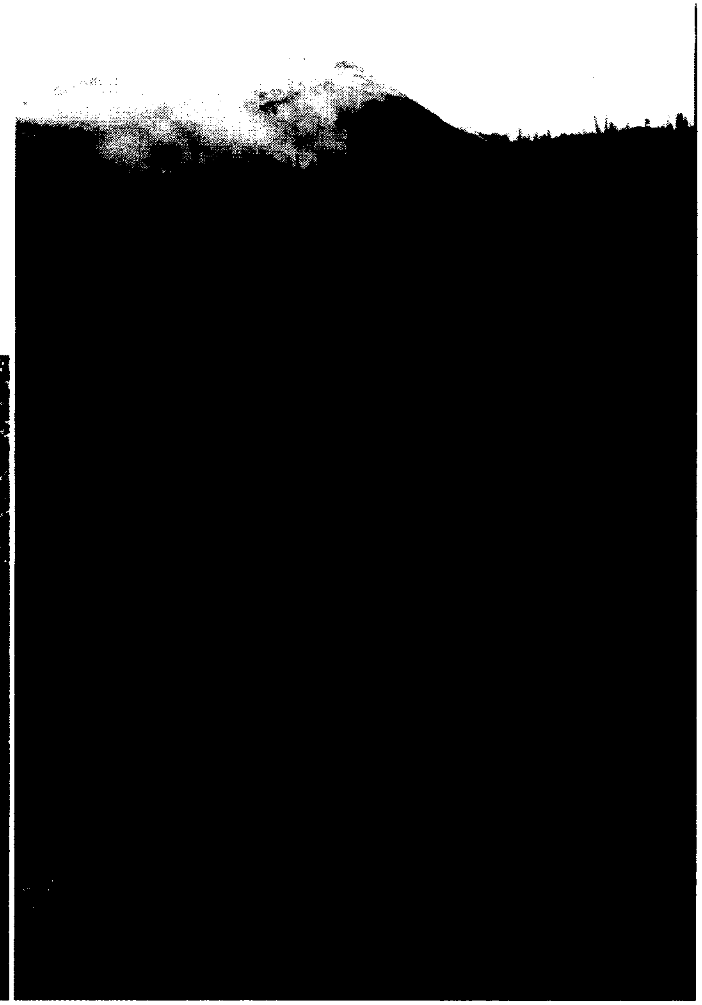
Riparian 3



Riparian 4

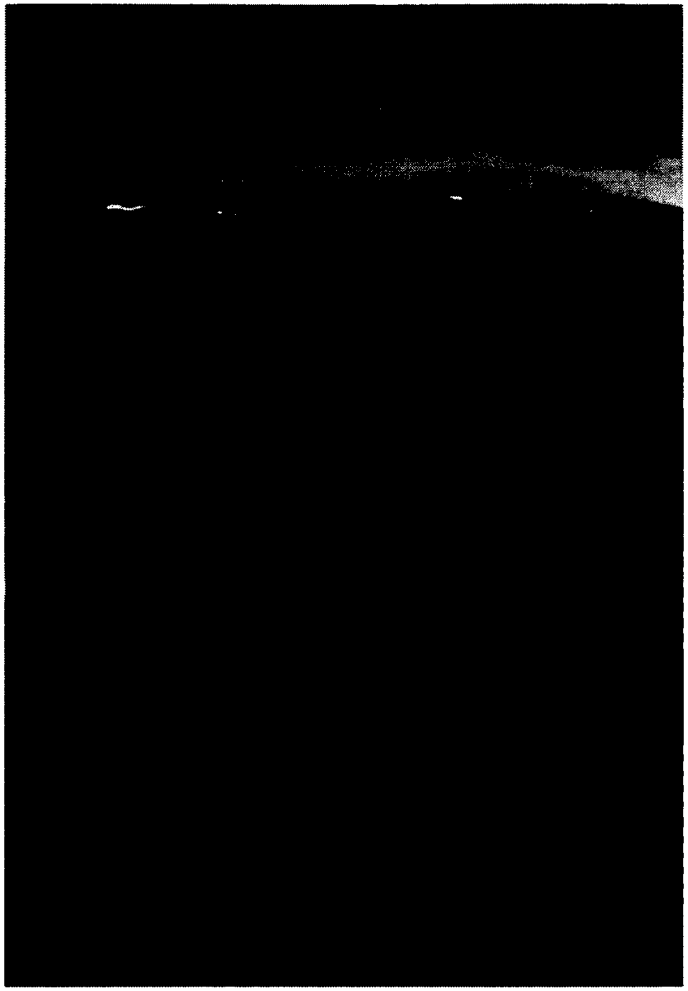
RIPARIAN CLASS – Continued

Riparian 5



Riparian 6

WATER CLASS



Water 1

Appendix E. Predation risk indices for inclusion in moose selection models.

Table E1. Seasonal resource selection function (RSF) models for wolves in northern British Columbia (BC) that were used to define relative predation risk to moose in the South Canol study area (see Milakovic (2008) for parameter coefficients). H = habitat class, E = elevation, A = aspect, S = slope, F = fragmentation (index of habitat diversity).

Moose Season	Seasonal RSF for Wolves in BC[1]
Calving	Denning: H x S x F x A
Summer	Late summer: H x S x F x A and H x S x A
Rut	Fall: H x S x F x A and H x S x A
Early winter	Winter: H x E x F x A
Late winter	Late winter: H x E x F x A

[1] Wolf seasons in northern BC: denning (1 May–31 Jul), late summer (1 Aug–30 Sep), fall (1 Oct–31 Dec), winter (1 Jan–23 Feb), late winter (1 Mar–31 Apr).

Table E2. Seasonal resource selection function (RSF) models for grizzly bears in northern British Columbia (BC) used to define relative predation risk to moose in the South Canol study area (see Milakovic (2008) for parameter coefficients). H = habitat class, E = elevation, A = aspect, F = fragmentation (index of habitat diversity).

Moose Season	Seasonal RSF for Grizzly Bears in BC[1]
Calving	Spring: H x E x F x A
Summer	Summer: H x E x F x A
Rut	Fall: H x E x F x A

[1] Bear seasons in northern BC: spring (den emergence - 15 Jun), summer (16 Jun–15 Aug), fall (16 Aug - denning)

Table E3. Habitat classes used in selection models for wolves and grizzly bears in northern British Columbia (BC) (Milakovic 2008) and comparable groupings of EOSD[1] classes modified by DEM[2] and NTDB[3] layers for the South Canol study area.

Wolf and bear habitat classes	EOSD Classes
Conifer	Coniferous Dense, Open
Stunted spruce	Coniferous Sparse
Shrub	Shrub Tall, Low
Alpine shrub	Shrub Tall, Low + DEM (above timberline)
Non-vegetated	Exposed Rock/Rubble, Snow/Ice, Water
Riparian spruce	Wetland Treed and Coniferous + NTDB (riparian buffer)
Open alpine	Herb & Bryoids + DEM (above timberline)
Deciduous burns	Broadleaf Dense, Open, Sparse and Shrub Tall, Low + wildfires
Elymus burns	Herb + wildfires[4]
Sub-alpine spruce	Coniferous Sparse + DEM

[1] EOSD = Earth Observation for Sustainable Development of Forests

[2]DEM = digital elevation model

[3]NTDB = National Topographic Database

[4]Wildfire polygons from Yukon Department of Energy, Mines and Resources

Appendix F. Seasonal resource selection function (RSF) model coefficients for individual male moose radio-collared in the South Canol area of south-central Yukon.

Table F1. Model parameters (Coef ± SE) of individual male moose during Late Winter in the South Canol area of south-central Yukon. Significant coefficients are in bold.

	Animal				
Parameter	**136***	**146***	**150**	**159***	**162***
Elevation (km)	**-3.01 ± 1.29**	**26.80 ± 0.73**	**42.82 ± 7.48**	**-10.39 ± 3.47**	**-1.84 ± 0.64**
Elevation (km)^2	0.99 ± 0.65	**-12.37 ± 0.33**	**-22.81 ± 4.03**	2.02 ± 1.25	**1.04 ± 0.29**
Eastness	**0.28 ± 0.02**	**-0.08 ± 0.02**	-0.08 ± 0.05	**0.34 ± 0.02**	**-0.08 ± 0.02**
Northness	**-0.34 ± 0.03**	**-0.18 ± 0.02**	0.00 ± 0.05	**-0.63 ± 0.03**	**-0.26 ± 0.02**
Wolf Risk	**-0.21 ± 0.05**	**0.18 ± 0.04**	**0.76 ± 0.16**	**0.34 ± 0.05**	**-0.08 ± 0.03**
Bear Risk	-	-	-	-	-
Conifer	**-0.58 ± 0.05**	**-0.32 ± 0.03**	**-0.51 ± 0.10**	**-0.74 ± 0.09**	**-0.13 ± 0.03**
Alpine	-	-	-	**0.27 ± 0.05**	**-1.01 ± 0.13**
Lowland Shrub	0.02 ± 0.04	**-0.19 ± 0.03**	**0.30 ± 0.12**	**-0.25 ± 0.05**	**0.54 ± 0.04**
Upland Shrub	**0.35 ± 0.14**	**0.33 ± 0.05**	-	**0.71 ± 0.04**	**-0.59 ± 0.04**
Mixed Wood	**0.16 ± 0.05**	0.08 ± 0.05	0.05 ± 0.13	**-0.89 ± 0.13**	**0.45 ± 0.04**
Riparian	0.05 ± 0.06	**0.82 ± 0.03**	**0.66 ± 0.11**	**0.90 ± 0.04**	**0.19 ± 0.04**
Water	-	-0.10 ± 0.13	**0.51 ± 0.21**	-	-
Lowland Open	-	**-0.62 ± 0.05**	**-1.01 ± 0.36**	-	**0.56 ± 0.12**
constant	0.57 ± 0.61	**-15.67 ± 0.39**	**-21.79 ± 3.43**	**7.90 ± 2.39**	**-0.98 ± 0.33**

* = averaged model

Table F2. Model parameters (Coef ± SE) of individual male moose during Calving in the South Canol area of south-central Yukon. Significant coefficients are in bold.

				Animal			
Parameter	**136***	**140**	**141***	**146**	**150**	**151**	**159**
Elevation (km)	**10.20 ± 1.69**	**-1.02 ± 3.00**	**-13.65 ± 1.20**	**34.94 ± 4.74**	-3.64 ± 3.23	**17.484 ± 4.619**	3.85 ± 2.64
Elevation $(km)^2$	**-6.63 ± 0.80**	**-1.02 ± 1.71**	**5.01 ± 0.53**	**-16.65 ± 2.15**	0.01 ± 1.43	**-10.075 ± 2.315**	-2.21 ± 1.14
Eastness	**-0.28 ± 0.03**	**-0.25 ± 0.08**	**0.08 ± 0.02**	**-0.65 ± 0.08**	-0.12 ± 0.07	**-0.428 ± 0.087**	0.04 ± 0.09
Northness	**0.78 ± 0.03**	-0.14 ± 0.10	**-0.39 ± 0.03**	-0.11 ± 0.09	-0.12 ± 0.07	0.161 ± 0.094	**-0.39 ± 0.07**
Wolf Risk	**-0.09 ± 0.03**	**0.18 ± 0.26**	**-0.36 ± 0.08**	**-0.74 ± 0.23**	**0.87 ± 0.21**	-0.059 ± 0.288	0.30 ± 0.24
Bear Risk	-0.11 ± 0.06	**1.16 ± 0.34**	**1.21 ± 0.13**	**1.28 ± 0.28**	**2.27 ± 0.33**	**1.861 ± 0.394**	**2.04 ± 0.59**
Conifer	**-0.70 ± 0.05**	**-0.44 ± 0.14**	**-0.33 ± 0.04**	**-1.23 ± 0.14**	**-1.23 ± 0.15**	**-0.426 ± 0.149**	-0.26 ± 0.14
Alpine	-	-	-	-0.47 ± 0.4	-	-	-0.13 ± 0.31
Lowland Shrub	**0.88 ± 0.05**	**-0.07 ± 0.15**	**0.44 ± 0.05**	**0.47 ± 0.13**	0.35 ± 0.16	**0.598 ± 0.173**	0.18 ± 0.14
Upland Shrub	-0.00 ± 0.16	**2.22 ± 0.47**	**0.75 ± 0.08**	**0.92 ± 0.21**	0.06 ± 0.26	**2.055 ± 0.475**	0.18 ± 0.14
Mixed Wood	**-0.31 ± 0.06**	**-0.23 ± 0.22**	**-0.59 ± 0.08**	**0.54 ± 0.21**	**-0.61 ± 0.19**	-0.292 ± 0.193	0.02 ± 0.20
Riparian	0.13 ± 0.07	**-0.01 ± 0.17**	**0.54 ± 0.05**	**-0.50± 0.18**	**0.40± 0.16**	0.362 ± 0.213	-0.14 ± 0.18
Water	-	-2.18 ± 0.41	**-2.06 ± 0.13**	-	0.88 ± 0.45	**-2.297 ± 0.439**	-
Lowland Open	-	0.71 ± 0.21	**1.25 ± 0.15**	0.26 ± 0.17	0.15 ± 0.50	-	0.15 ± 0.50
constant	**-4.78 ± 0.85**	-0.75 ± 1.16	**6.58± 0.65**	**-19.54 ± 2.54**	0.79 ± 1.66	**-9.62 ± 2.24**	**-4.90 ± 1.53**

* = averaged model

Table F2. Continued.

Parameter	162*
Elevation (km)	**4.81 ± 0.79**
Elevation $(km)^2$	**-2.74 ± 0.40**
Eastness	**-0.24 ± 0.02**
Northness	**-0.07 ± 0.03**
Wolf Risk	-0.05 ± 0.05
Bear Risk	**0.24 ± 0.04**
Conifer	**-0.29 ± 0.04**
Alpine	-
Lowland Shrub	**0.66 ± 0.05**
Upland Shrub	**-0.60 ± 0.13**
Mixed Wood	-0.04 ± 0.06
Riparian	**0.61 ± 0.05**
Water	-
Lowland Open	**-0.34 ± 0.14**
constant	**-3.87 ± 0.37**

Table F3. Model parameters (Coef ± SE) of individual male moose during Summer in the South Canol area of south-central Yukon. Significant coefficients are in bold.

				Animal			
Parameter	**140**	**150**	**136***	**141***	**146***	**159***	**162***
Elevation (km)	**-21.75 ± 4.1**	**12.65 ± 2.55**	-0.71 ± 1.20	**11.64 ± 0.94**	**84.65 ± 4.90**	**18.29 ± 0.95**	**36.60 ± 1.83**
Elevation $(km)^2$	**9.39 ± 1.80**	**-6.05± 1.05**	-0.72 ± 0.59	**-5.86 ± 0.41**	**-40.81 ± 2.22**	**-9.19 ± 0.38**	**-16.42 ± 0.9**
Eastness	**0.51 ± 0.10**	**-0.20 ± 0.08**	**-0.12 ± 0.03**	**0.52 ± 0.02**	**0.10 ± 0.02**	**-0.10 ± 0.02**	**-0.66 ± 0.04**
Northness	**0.32 ± 0.08**	0.06 ± 0.07	**0.09 ± 0.04**	**0.23 ± 0.03**	-0.01 ± 0.02	**-0.61 ± 0.03**	**0.12 ± 0.03**
Wolf Risk	**0.80 ± 0.25**	0.32 ± 0.24	**-0.09 ± 0.04**	**0.22 ± 0.07**	**-0.45± 0.08**	-0.05 ± 0.02	**-0.74 ± 0.10**
Bear Risk	**-0.68 ± 0.21**	**0.41 ± 0.19**	-0.02 ± 0.02	**0.30 ± 0.06**	0.04 ± 0.09	-0.00 ± 0.02	**0.30 ± 0.07**
Conifer	-0.09 ± 0.14	-0.58 ± 0.12	**-0.70 ± 0.04**	-0.12 ± 0.04	**-0.44± 0.03**	**-0.78 ± 0.07**	**-0.59 ± 0.04**
Alpine	**-0.81 ± 0.35**	0.08 ± 0.26	-	0.19 ± 0.11	-	**0.63 ± 0.09**	**0.26 ± 0.13**
Lowland Shrub	0.33 ± 0.22	0.13 ± 0.15	**-0.26 ± 0.05**	**-0.67 ± 0.07**	**0.45 ± 0.03**	**-0.53 ± 0.07**	**0.23 ± 0.05**
Upland Shrub	**0.48 ± 0.14**	**0.60 ± 0.15**	**0.24 ± 0.11**	**1.41 ± 0.05**	-	**1.59 ± 0.05**	**0.76 ± 0.05**
Mixed Wood	020 ± 0.19	**-0.50 ± 0.19**	**-0.31 ± 0.07**	**-1.09 ± 0.13**	**-0.20 ± 0.06**	**-0.64 ± 0.11**	**-0.23 ± 0.05**
Riparian	-0.11 ± 0.29	0.21 ± 0.17	**0.43 ± 0.06**	**0.75 ± 0.05**	**0.35 ± 0.04**	**-0.26 ± 0.08**	**-0.42 ± 0.06**
Water	-	-	**0.60 ± 0.08**	-	**-0.41 ± 0.08**	-	-
Lowland Open	-	0.07 ± 0.40	-	**-0.47 ± 0.13**	**0.26 ± 0.07**	-	-
constant	**10.44 ± 2.39**	**-7.95 ± 1.51**	0.23 ± 0.59	**-7.57 ± 0.52**	-44.70 ± 2.69	**-9.68 ± 0.59**	**-21.66 ± 1.06**

* = averaged model

Table F4. Model parameters (Coef ± SE) of individual male moose during Rut in the South Canol area of south-central Yukon. Significant coefficients are in bold.

				Animal			
Parameter	**136***	**140***	**141***	**146**	**150***	**151***	**159***
Elevation (km)	**8.86 ± 0.81**	**2.43 ± 0.76**	**9.19 ± 0.74**	**-15.60 ± 390**	**3.049 ± 0.49**	**2.89 ± 0.85**	**53.37 ± 2.66**
Elevation $(km)^2$	**-3.77 ± 0.32**	**-1.02 ± 0.31**	**-4.71 ± 0.31**	**4.35 ± 1.76**	**-1.95± 0.20**	**-1.64 ± 0.34**	**-20.46 ± 0.94**
Eastness	**-0.61 ± 0.03**	**0.05 ± 0.02**	**0.06 ± 0.02**	**0.23 ± 0.05**	**0.13 ± 0.016**	**0.39 ± 0.02**	-0.04 ± 0.02
Northness	**0.88 ± 0.03**	**0.52 ± 0.02**	**-0.25 ± 0.02**	**0.32 ± 0.07**	**0.27 ± 0.02**	**0.08 ± 0.02**	**0.13 ± 0.02**
Wolf Risk	**0.54 ± 0.07**	**0.38 ± 0.06**	**-0.16 ± 0.05**	-0.25 ± 0.18	**-0.55 ± 0.05**	**-0.60 ± 0.07**	**0.14 ± 0.05**
Bear Risk	**-0.87 ± 0.08**	**0.71 ± 0.07**	**0.57 ± 0.06**	**-0.84 ± 0.25**	**0.45 ± 0.05**	**1.07 ± 0.10**	**-0.30 ± 0.06**
Harvest Risk	**-47.05 ± 5.89**	0.02 ± 0.08	0.13 ± 0.21	**-2.30 ± 0.90**	**-1.19 ± 0.18**	**-1.39 ± 0.56**	-
Conifer	**-0.79 ± 0.04**	**-0.14 ± 0.03**	**-0.64 ± 0.03**	**-0.92 ± 0.13**	**-0.63 ± 0.02**	**-0.74 ± 0.03**	**-0.59 ± 0.03**
Alpine	**-0.52 ± 0.08**	**-1.04 ± 0.09**	**0.49 ± 0.07**	-0.17 ± 0.54	**-0.56 ± 0.05**	-0.00 ± 0.07	**-0.60 ± 0.06**
Lowland Shrub	**-0.38 ± 0.05**	**-0.50 ± 0.05**	**0.28 ± 0.04**	**0.303 ± 0.14**	**0.30 ± 0.03**	-0.03 ± 0.05	**0.50 ± 0.04**
Upland Shrub	**1.30 ± 0.05**	**0.91 ± 0.03**	**1.03 ± 0.04**	**1.51 ± 0.19**	**0.48 ± 0.03**	**1.06 ± 0.04**	**0.43 ± 0.03**
Mixed Wood	**-0.34 ± 0.05**	**-0.27 ± 0.05**	**-0.67 ± 0.08**	-0.34 ± 0.20	**-0.14 ± 0.03**	**-0.63 ± 0.05**	**-0.17 ± 0.05**
Riparian	**0.80 ± 0.05**	**1.03± 0.05**	**0.38 ± 0.04**	-0.15 ± 0.15	**0.74 ± 0.03**	**0.46 ± 0.05**	**0.43 ± 0.04**
Water	-0.07 ± 0.14	-	**-0.25 ± 0.08**	**-0.90 ± 0.37**	-	**-1.13 ± 0.12**	-
Lowland Open	-	-	**-0.61 ± 0.14**	**0.66 ± 0.19**	**-0.18 ± 0.08**	**1.01 ± 0.12**	-
constant	**-6.54 ± 0.50**	**-4.01 ± 0.45**	**-5.94 ± 0.43**	**11.06 ± 2.08**	**-2.22 ± 0.29**	**-2.91 ± 0.52**	**-35.90 ± 1.88**

* = averaged model

Table F4. Continued.

Parameter	**162***
Elevation (km)	**17.45 ± 0.79**
Elevation $(km)^2$	**-8.06 ± 0.32**
Eastness	**-0.10 ± 0.02**
Northness	**0.06 ± 0.02**
Wolf Risk	**-0.06 ± 0.03**
Bear Risk	-0.03 ± 0.02
Harvest Risk	-
Conifer	**-0.23 ± 0.03**
Alpine	**-0.17 ± 0.08**
Lowland Shrub	**-0.48 ± 0.04**
Upland Shrub	**1.06 ± 0.03**
Mixed Wood	**-0.35 ± 0.05**
Riparian	**0.16 ± 0.05**
Water	-
Lowland Open	-
constant	**-10.63 ± 0.47**

Table F5. Model parameters (Coef ± SE) of individual male moose during Early Winter in the South Canol area of south-central Yukon. Significant coefficients are in bold.

	Animal						
Parameter	**136***	**140***	**141***	**146***	**150***	**151***	**159**
Elevation (km)	**28.97 ± 1.95**	**17.18 ± 0.81**	**5.31 ± 0.48**	**16.11 ± 0.53**	**10.12 ± 0.44**	**43.99 ± 2.91**	16.52 ± 9.09
Elevation $(km)^2$	**-11.92 ± 0.78**	**-7.00 ± 0.32**	**-2.60 ± 0.23**	**-7.12 ± 0.21**	**-4.49 ± 0.19**	**-20.78 ± 1.41**	**-6.72 ± 3.17**
Eastness	**-0.17 ± 0.02**	**-0.29 ± 0.02**	**0.12 ± 0.02**	**-0.10 ± 0.01**	0.01 ± 0.01	**-0.05 ± 0.02**	**-0.17 ± 0.05**
Northness	**0.09 ± 0.03**	**0.10 ± 0.01**	**-0.06 ± 0.01**	**0.18 ± 0.01**	**0.16 ± 0.02**	**-0.17 ± 0.02**	**-0.11 ± 0.05**
Wolf Risk	**-0.36 ± 0.06**	-0.00 ± 0.02	**0.07 ± 0.02**	0.01 ± 0.01	0.02 ± 0.01	**-0.07 ± 0.03**	**0.61 ± 0.16**
Conifer	**-1.22 ± 0.05**	**-1.22 ± 0.03**	**-0.65 ± 0.03**	**-0.76 ± 0.03**	**-0.84 ± 0.04**	**-0.11 ± 0.04**	**-0.64 ± 0.17**
Alpine	**-0.58 ± 0.09**	**-0.95 ± 0.06**	**-0.93 ± 0.12**	**-0.36 ± 0.05**	**-0.92 ± 0.07**	-	0.18 ± 0.12
Lowland Shrub	**0.24 ± 0.04**	0.04 ± 0.03	**0.34 ± 0.03**	**0.18 ± 0.04**	**0.15 ± 0.03**	**0.20 ± 0.04**	-0.07 ± 0.16
Upland Shrub	**0.56 ± 0.04**	**-0.26 ± 0.04**	**0.41 ± 0.04**	**0.69 ± 0.03**	**0.53 ± 0.04**	-	**0.42 ± 0.09**
Mixed Wood	**-0.62 ± 0.06**	**-0.93 ± 0.05**	-0.09 ± 0.05	-0.08 ± 0.06	**-0.82 ± 0.06**	**-0.33 ± 0.05**	**-0.61 ± 0.28**
Riparian	**1.61 ± 0.04**	**0.54 ± 0.04**	**0.96 ± 0.03**	**0.87 ± 0.03**	**1.17 ± 0.03**	**0.79 ± 0.05**	**0.72 ± 0.10**
Water	-	**3.58 ± 0.15**	-0.04 ± 0.06	**-0.68 ± 0.13**	**0.73 ± 0.15**	**-0.55 ± 0.12**	-
Lowland Open	-	**-0.78 ± 0.08**	-0.01 ± 0.12	**0.14 ± 0.07**	0.00 ± 0.11	-	-
constant	**-19.06 ± 1.22**	**-11.59 ± 0.51**	**-4.27 ± 0.24**	**-10.21 ± 0.33**	**-7.23 ± 0.25**	**-24.62 ± 1.49**	-12.11 ± 6.49

* = averaged model

Appendix G. Seasonal resource selection function (RSF) model coefficients for individual female moose radio-collared in the South Canol area of south-central Yukon.

Table G1. Model parameters (Coef ± SE) of individual female moose during Late Winter in the South Canol area of south-central Yukon. Significant coefficients are in bold.

	Animal						
Parameter	**138**	**145**	**148**	**149**	**153**	**147***	**152***
Elevation (km)	**49.44 ± 8.81**	**-53.46 ± 18.14**	**-12.44 ± 6.10**	3.32 ± 15.50	**-52.13 ± 6.61**	-5.13 ± 2.87	**58.36 ± 6.55**
Elevation $(km)^2$	**-23.44 ± 4.06**	**25.07 ± 8.61**	5.58 ± 3.04	-1.29 ± 6.77	**24.71 ± 3.13**	1.39 ± 1.57	**-28.56 ± 3.11**
Eastness	-0.03 ± 0.07	0.28 ± 0.16	**-0.41 ± 0.13**	**0.31 ± 0.08**	**-0.24 ± 0.10**	**1.19 ± 0.05**	-0.04 ± 0.02
Northness	**-0.20 ± 0.10**	**-0.66 ± 0.24**	-0.24 ± 0.14	0.06 ± 0.08	**0.31 ± 0.09**	0.07 ± 0.04	**0.31 ± 0.02**
Wolf Risk	**-0.71 ± 0.26**	0.50 ± 0.58	**0.93 ± 0.47**	0.14 ± 0.37	-0.16 ± 0.30	**-0.84 ± 0.15**	**0.51 ± 0.08**
Bear Risk	**1.66 ± 0.20**	**-2.34 ± 0.76**	**1.30 ± 0.56**	**-1.10 ± 0.41**	**1.46 ± 0.38**	-0.19 ± 0.17	**-0.53 ± 0.10**
Conifer	**-0.55 ± 0.15**	**-1.07 ± 0.23**	**-0.39 ± 0.14**	-0.01 ± 0.09	0.11 ± 0.13	**0.10 ± 0.04**	**-0.17 ± 0.03**
Alpine	-	-	-	-	-	-	-
Lowland Shrub	0.25 ± 0.15	0.36 ± 0.27	0.30 ± 0.20	-0.23 ± 0.11	**0.50 ± 0.17**	**-0.18 ± 0.06**	-0.06 ± 0.03
Upland Shrub	0.70 ± 0.40	0.58 ± 0.42	-	-	-	-	-
Mixed Wood	-0.30 ± 0.18	-	-0.29 ± 0.28	0.28 ± 0.15	**0.58 ± 0.24**	**0.55 ± 0.08**	**0.27 ± 0.06**
Riparian	**0.61 ± 0.19**	0.13 ± 0.39	**0.35 ± 0.17**	**0.60 ± 0.13**	-0.09 ± 0.14	**-0.22 ± 0.08**	**0.46 ± 0.03**
Water	-0.16 ± 0.53	-	0.02 ± 0.29	-	**-1.10 ± 0.35**	**-0.25 ± 0.12**	**-0.15 ± 0.06**
Lowland Open	-0.55 ± 0.47	-	-	**-0.63 ± 0.21**	-	-	**-0.35 ± 0.06**
constant	**-27.81 ± 4.72**	**26.56 ± 9.06**	3.72 ± 2.86	-3.24 ± 8.83	**23.19 ± 3.25**	1.482 ± 1.27	**-31.34 ± 3.44**

* = averaged model

Table G1. Continued.

Parameter	**158***	**160***	**161***
Elevation (km)	**2.75 ± 0.88**	-0.47 ± 0.66	**35.12 ± 1.87**
Elevation (km)^2	**-1.38 ± 0.36**	0.21 ± 0.27	**-15.04 ± 0.77**
Eastness	**-0.56 ± 0.04**	**-0.20 ± 0.03**	**-0.09 ± 0.03**
Northness	**-0.35 ± 0.04**	**0.16 ± 0.03**	**-0.08 ± 0.03**
Wolf Risk	**0.25 ± 0.09**	**-0.6 ± 0.09**	-0.03 ± 0.03
Bear Risk	**0.49 ± 0.09**	-0.10 ± 0.08	**0.06 ± 0.03**
Conifer	0.01 ± 0.06	**0.45 ± 0.04**	**0.36 ± 0.04**
Alpine	**-1.01 ± 0.12**	**-2.49 ± 0.15**	-
Lowland Shrub	**-0.38 ± 0.08**	-0.10 ± 0.06	-0.03 ± 0.04
Upland Shrub	**0.71 ± 0.05**	**0.57 ± 0.04**	**0.65± 0.05**
Mixed Wood	**-0.44 ± 0.12**	**0.70 ± 0.06**	**0.18 ± 0.05**
Riparian	**1.11 ± 0.07**	**0.87 ± 0.07**	**-1.16 ± 0.09**
Water	-	-	-
Lowland Open	-	-	-
constant	**-3.48 ± 0.53**	**-1.52± 0.41**	**-21.51 ± 1.13**

Table G2. Model parameters (Coef ± SE) of individual female moose during Calving in the South Canol area of south-central Yukon. Significant coefficients are in bold.

				Animal			
Parameter	**138**[1]	**143**[2]	**144**[2]	**145**[3]	**147**[3]	**148**[2]	**149**[1]
Elevation (km)	-4.93 ± 4.03	25.03 ± 101.83	**38.40 ± 12.34**	**-27.15 ± 13.31**	-1.72 ± 7.37	5.42 ± 54.49	**18.2 ± 7.63**
Elevation $(km)^2$	3.04 ± 1.89	-19.00 ± 65.31	**-23.41 ± 6.48**	**15.54 ± 6.64**	-1.62 ± 4.06	-43.58 ± 35.05	**-8.43 ± 3.41**
Eastness	**-0.68 ± 0.08**	**1.11 ± 0.17**	**0.31 ± 0.14**	**-0.31± 0.13**	0.03 ± 0.10	**-0.41 ± 0.14**	**-0.35 ± 0.08**
Northness	**-0.50 ± 0.09**	-0.08 ± 0.23	**-0.77 ± 0.14**	**0.68 ± 0.15**	-0.15 ± 0.09	**-0.80 ± 0.16**	**0.42 ± 0.08**
Wolf Risk	**0.83 ± 0.23**	-1.05 ± 0.57	-0.79 ± 0.43	**1.69 ± 0.31**	**0.86 ± 0.33**	**-2.70 ± 0.42**	**-0.66 ± 0.19**
Bear Risk	**1.92 ± 0.39**	**6.52 ± 1.42**	**3.42 ± 0.53**	-0.32 ± 0.28	0.36 ± 0.55	**14.17 ± 0.92**	0.27 ± 0.40
Conifer	**-0.39 ± 0.12**	-0.07 ± 0.18	**-0.89 ± 0.14**	**-0.63 ± 0.14**	-0.11 ± 0.14	0.17 ± 0.18	**-0.28 ± 0.10**
Alpine	0.02 ± 0.36	-	-	-	-	-	-
Lowland Shrub	0.29 ± 0.15	**0.42 ± 0.21**	**0.72 ± 0.14**	0.16 ± 0.23	**1.18 ± 0.15**	**-0.73 ± 0.37**	**0.30 ± 0.10**
Upland Shrub	0.21 ± 0.21	-	-	-	-	-	-
Mixed Wood	0.05 ± 0.15	-	-0.49 ± 0.26	-0.18 ± 0.28	**0.47 ± 0.23**	0.64 ± 0.44	**0.66 ± 0.14**
Riparian	-0.19 ± 0.23	0.12 ± 0.23	**0.66 ± 0.19**	**0.66 ± 0.18**	**-0.44 ± 0.22**	-0.13 ± 0.22	0.11 ± 0.18
Water	-	-0.48 ± 0.36	-	-	**-1.1 ± 0.39**	0.05 ± 0.28	-
Lowland Open	-	-	-	-	-	-	**-0.79 ± 0.23**
constant	-1.92 ± 1.95	-10.72 ± 39.62	**-17.14 ± 5.91**	9.63 ± 6.57	-0.05 ± 3.24	13.77 ± 21.10	**-11.29 ± 4.19**

[1] Calf always present

[2] Calf never present

[3] Calf only present in 1 of 2 years

Table G2. Continued.

Parameter	**152**[3]	**153**[3]	**154**[2]	**157**[3]	**160***[3]	**161***[3]
Elevation (km)	**64.13 ± 14.12**	**-53.37± 10.08**	**-123.79 ± 18.22**	5.52 ± 3.04	**46.30 ± 2.87**	**5.15 ± 0.61**
Elevation $(km)^2$	**-26.73 ± 5.65**	**28.09 ± 5.56**	**48.62 ± 6.84**	-2.55 ± 1.53	**-20.24 ± 1.23**	**-2.54 ± 0.27**
Eastness	0.02 ± 0.06	0.12 ± 0.08	-0.15 ± 0.20	**0.27 ± 0.07**	**0.09 ± 0.03**	**-0.102 ± 0.02**
Northness	-0.03 ± 0.06	**0.18 ± 0.08**	**-0.65 ± 0.23**	**0.27 ± 0.09**	**0.28 ± 0.02**	0.04 ± 0.02
Wolf Risk	**-0.58 ± 0.20**	**-0.72± 0.24**	**2.78± 0.87**	**0.78 ± 0.23**	0.00 ± 0.01	**-0.51 ± 0.06**
Bear Risk	**1.31 ± 0.40**	**0.92 ± 0.29**	**-9.03 ± 2.32**	0.23 ± 0.30	**-0.08 ± 0.03**	**0.40 ± 0.11**
Conifer	**-0.82 ± 0.14**	**-0.54 ± 0.12**	**-3.81 ± 1.15**	-0.29 ± 0.15	**-0.49 ± 0.04**	**0.18 ± 0.03**
Alpine	0.16 ± 0.54	-	3.40 ± 1.81	-	**0.48 ± 0.12**	**-1.35 ± 0.11**
Lowland Shrub	**0.47 ± 0.14**	0.15 ± 0.15	-2.01 ± 1.20	**0.49 ± 0.16**	0.05 ± 0.05	**0.34 ± 0.04**
Upland Shrub	**1.02 ± 0.23**	-	**4.48 ± 1.71**	0.72 ± 0.56	0.07 ± 0.12	**0.48 ± 0.05**
Mixed Wood	-0.27 ± 0.16	0.40 ± 0.22	-	0.30± 0.20	-0.13 ± 0.05	**0.21 ± 0.05**
Riparian	**0.45 ± 0.17**	0.12 ± 0.12	-2.07 ± 1.22	**0.41 ± 0.19**	0.02 ± 0.06	**0.14 ± 0.06**
Water	**-0.94 ± 0.37**	0.08 ± 0.19	-	-0.69 ± 0.37	-	-
Lowland Open	-0.06 ± 0.30	-0.21 ± 0.34	-	**-0.94 ± 0.44**	-	-
constant	**-40.24 ± 8.65**	**23.11 ± 4.46**	**70.67 ± 11.21**	**-5.20 ± 1.49**	**-27.58 ± 1.65**	**-4.31 ± 0.31**

* = averaged model

[2] Calf never present

[3] Calf only present in 1 of 2 years

Table G3. Model parameters (Coef ± SE) of individual female moose during Summer in the South Canol area of south-central Yukon. Significant coefficients are in bold.

				Animal			
Parameter	**138**	**145**	**148**	**149**	**153**	**147***	**152***
Elevation (km)	**49.44 ± 8.81**	**-53.46 ± 18.14**	**-12.44 ± 6.10**	**3.32 ± 15.50**	**-52.13 ± 6.61**	**-5.13 ± 2.87**	**58.36 ± 6.55**
Elevation $(km)^2$	**-23.44 ± 4.06**	**25.07 ± 8.61**	5.58 ± 3.04	-1.29 ± 6.77	**24.71 ± 3.13**	1.39 ± 1.57	**-28.56 ± 3.11**
Eastness	-0.03 ± 0.07	0.28 ± 0.16	**-0.41 ± 0.13**	**0.31 ± 0.08**	**-0.24 ± 0.10**	**1.19 ± 0.05**	-0.04 ± 0.02
Northness	**-0.20 ± 0.10**	**-0.66 ± 0.24**	-0.24 ± 0.14	0.06 ± 0.08	**0.31 ± 0.09**	0.07 ± 0.04	**0.31 ± 0.02**
Wolf Risk	**-0.71 ± 0.26**	0.50 ± 0.58	**0.93 ± 0.47**	0.14 ± 0.37	-0.16 ± 0.30	**-0.84 ± 0.15**	**0.51 ± 0.08**
Bear Risk	**1.66 ± 0.20**	**-2.34 ± 0.76**	**1.30 ± 0.56**	**-1.10 ± 0.41**	**1.46 ± 0.38**	-0.19 ± 0.17	**-0.53 ± 0.10**
Conifer	**-0.55 ± 0.15**	**-1.07 ± 0.23**	**-0.39 ± 0.14**	-0.01 ± 0.09	0.11 ± 0.13	**0.10 ± 0.04**	**-0.17 ± 0.03**
Alpine	-	-	-	-	-	-	-
Lowland Shrub	0.25 ± 0.15	0.36 ± 0.27	0.30 ± 0.20	-0.23 ± 0.11	**0.50 ± 0.17**	**-0.18 ± 0.06**	-0.06 ± 0.03
Upland Shrub	0.70 ± 0.40	0.58 ± 0.42	-	-	-	-	-
Mixed Wood	-0.30 ± 0.18	-	-0.29 ± 0.28	0.28 ± 0.15	**0.58 ± 0.24**	**0.55 ± 0.08**	**0.27 ± 0.06**
Riparian	**0.61 ± 0.19**	0.13 ± 0.39	**0.35 ± 0.17**	**0.60 ± 0.13**	-0.09 ± 0.14	**-0.22 ± 0.08**	**0.46 ± 0.03**
Water	-0.16 ± 0.53	-	0.02 ± 0.29	-	**-1.10 ± 0.35**	**-0.25 ± 0.12**	**-0.15 ± 0.06**
Lowland Open	-0.55 ± 0.47	-	-	**-0.63 ± 0.21**	-	-	**-0.35 ± 0.06**
constant	**-27.81 ± 4.72**	**26.56 ± 9.06**	3.72 ± 2.86	-3.24 ± 8.83	**23.19 ± 3.25**	1.48 ± 1.27	**-31.34 ± 3.44**

* = averaged model

Table G3. Continued.

Parameter	**160***	**161***
Elevation (km)	**-0.47 ± 0.66**	**35.12 ± 1.87**
Elevation $(km)^2$	0.21 ± 0.27	**-15.04 ± 0.77**
Eastness	**-0.20 ± 0.03**	**-0.09 ± 0.03**
Northness	**0.16 ± 0.03**	**-0.08 ± 0.03**
Wolf Risk	**-0.6 ± 0.09**	-0.03 ± 0.03
Bear Risk	-0.10 ± 0.08	**0.06 ± 0.03**
Conifer	**0.45 ± 0.04**	**0.36 ± 0.04**
Alpine	**-2.49 ± 0.15**	-
Lowland Shrub	-0.10 ± 0.06	-0.03 ± 0.04
Upland Shrub	**0.57 ± 0.04**	**0.65± 0.05**
Mixed Wood	**0.70 ± 0.06**	**0.18 ± 0.05**
Riparian	**0.87 ± 0.07**	**-1.16 ± 0.09**
Water	-	-
Lowland Open	-	-
constant	**-1.52± 0.41**	**-21.51 ± 1.13**

Table G4. Model parameters (Coef ± SE) of individual female moose during Rut in the South Canol area of south-central Yukon. Significant coefficients are in bold.

	Animal						
Parameter	**138**	**145**	**148**	**153**	**158**	**149***	**152***
Elevation (km)	**36.17 ± 10.5**	3.38 ± 4.47	4.66 ± 3.30	**-15.14 ± 2.86**	**24.94 ± 4.60**	**-6.03± 2.40**	**44.42 ± 2.28**
Elevation (km)^2	**-14.44 ± 4.20**	-1.61 ± 1.71	-2.70 ± 1.54	**7.25 ± 1.35**	**-10.06 ± 1.59**	**3.49 ± 1.01**	**-17.33 ± 0.91**
Eastness	**-0.11 ± 0.05**	**0.22 ± 0.09**	0.15 ± 0.10	**-0.23 ± 0.07**	0.17 ± 0.11	**-0.21 ± 0.02**	**0.25 ± 0.02**
Northness	**0.15 ± 0.07**	**-0.49 ± 0.11**	**-0.21 ± 0.10**	**0.29 ± 0.06**	**-0.17± 0.08**	**-0.16 ± 0.02**	**0.26 ± 0.02**
Wolf Risk	-0.02 ± 0.20	**1.87 ± 0.55**	**1.04 ± 0.35**	**0.72 ± 0.19**	**1.01 ± 0.33**	-0.04 ± 0.02	**0.78 ± 0.11**
Bear Risk	**0.71 ± 0.25**	-1.13 ± 0.58	0.42 ± 0.38	**0.70 ± 0.20**	**-1.62 ± 0.45**	0.01 ± 0.02	-0.11 ± 0.11
Conifer	**-0.33 ± 0.10**	0.18 ± 0.17	**-0.52 ± 0.16**	-0.16 ± 0.10	-0.46 ± 0.20	**0.15 ± 0.03**	**-0.41 ± 0.04**
Alpine	0.28 ± 0.22	**-0.64 ± 0.32**	-0.19 ± 0.39	-	**0.73 ± 0.19**	-	**0.44 ± 0.15**
Lowland Shrub	**0.44 ± 0.10**	**-1.89 ± 0.44**	**0.91 ± 0.19**	**0.31 ± 0.13**	**-1.44 ± 0.35**	**0.19 ± 0.03**	**-0.25 ± 0.04**
Upland Shrub	0.13 ± 0.12	**1.58 ± 0.16**	**0.78 ± 0.19**	**-1.52 ± 0.37**	**0.74 ± 0.13**	**-0.99 ± 0.11**	**1.09 ± 0.07**
Mixed Wood	**-0.36 ± 0.15**	-0.11 ± 0.42	**-1.15 ± 0.33**	0.27 ± 0.17	0.02 ± 0.30	**0.47± 0.04**	**-0.31 ± 0.05**
Riparian	0.04 ± 0.14	**0.88 ± 0.28**	**0.83 ± 0.18**	**0.43 ± 0.11**	**0.42 ± 0.21**	**0.31 ± 0.05**	**-0.23 ± 0.05**
Water	-	-	**-0.65 ± 0.30**	**0.47 ± 0.18**	-	0.12± 0.07	-0.11 ± 0.10
Lowland Open	-0.20 ± 0.34	-	-	0.20 ± 0.30	-	**-0.25 ± 0.05**	**-0.23 ± 0.08**
constant	**-24.74 ± 6.46**	-4.40 ± 2.84	**-4.28 ± 1.61**	**4.83 ± 1.38**	**-16.08 ± 3.26**	0.46 ± 1.42	**-29.86 ± 1.41**

* = averaged model

Table G4. Continued.

Parameter	155*	160*	161*
Elevation (km)	**-12.62 ± 0.88**	**6.75± 0.59**	**16.56 ± 0.94**
Elevation $(km)^2$	**4.76 ± 0.37**	**-2.95 ± 0.24**	**-7.02 ± 0.38**
Eastness	**-0.16 ± 0.02**	**-0.30± 0.02**	**-0.39 ± 0.02**
Northness	**-0.13 ± 0.02**	**-0.14 ± 0.02**	**0.22 ± 0.02**
Wolf Risk	**-0.27 ± 0.05**	**-0.22 ± 0.04**	**0.10 ± 0.04**
Bear Risk	**0.20 ± 0.06**	**0.11 ± 0.04**	**0.20 ± 0.06**
Conifer	**-0.12 ± 0.04**	**-0.39 ± 0.03**	**-0.31 ± 0.03**
Alpine	**-2.46 ± 0.15**	**-0.98 ± 0.07**	**-0.59± 0.06**
Lowland Shrub	**0.85± 0.05**	**0.24 ± 0.03**	**0.46 ± 0.04**
Upland Shrub	**1.22 ± 0.05**	**0.55 ± 0.03**	**0.60± 0.03**
Mixed Wood	**0.31 ± 0.06**	-0.08 ± 0.05	**-0.12 ± 0.05**
Riparian	**0.88 ± 0.04**	**0.66± 0.04**	**-0.40 ± 0.05**
Water	**-1.24 ± 0.09**	-	-
Lowland Open	**0.56± 0.15**	-	**0.36 ± 0.15**
constant	**5.97 ± 0.50**	**-5.373 ± 0.36**	**-11.45 ± 0.59**

Table G5. Model parameters (Coef ± SE) of individual female moose during Early Winter in the South Canol area of south-central Yukon. Significant coefficients are in bold.

	Animal						
Parameter	**138**	**158**	**144***	**147***	**152***	**153***	**155***
Elevation (km)	**11.45 ± 3.04**	**9.42 ± 2.89**	**10.63 ± 0.75**	**1.84 ± 0.68**	**9.77 ± 1.04**	**8.89 ± 0.89**	**-1.56 ± 0.42**
Elevation $(km)^2$	**-5.44 ± 1.38**	**-4.49 ± 1.00**	**-5.2 ± 0.36**	**-1.20 ± 0.34**	**-5.433 ± 0.48**	**-4.35 ± 0.44**	**0.95 ± 0.19**
Eastness	-0.05 ± 0.05	0.12 ± 0.08	**0.05 ± 0.02**	**-0.19 ± 0.02**	**-0.17 ± 0.03**	**0.06 ± 0.02**	**-0.09 ± 0.01**
Northness	**0.22 ± 0.06**	**-0.45 ± 0.08**	**0.61 ± 0.03**	**-0.16 ± 0.02**	**-0.33 ± 0.03**	**0.19 ± 0.02**	**0.23 ± 0.02**
Wolf Risk	**0.46 ± 0.16**	**0.88 ± 0.23**	**-0.29 ± 0.06**	**-0.30 ± 0.05**	0.04 ± 0.03	0.02 ± 0.02	**0.04 ± 0.02**
Bear Risk	-	-	-	-	-	-	-
Conifer	**-0.85 ± 0.07**	**-1.23 ± 0.28**	**-1.00 ± 0.04**	**-0.58 ± 0.04**	**-1.16 ± 0.05**	**-0.35 ± 0.04**	**-0.16 ± 0.02**
Alpine	0.29 ± 0.19	0.28 ± 0.17	**-1.91 ± 0.16**	**-0.98 ± 0.12**	**0.82 ± 0.12**	-	**-2.60 ± 0.10**
Lowland Shrub	-0.02 ± 0.08	-0.02 ± 0.20	**0.25 ± 0.05**	**0.29 ± 0.04**	**-0.30 ± 0.07**	**0.20 ± 0.04**	**0.77 ± 0.03**
Upland Shrub	0.17 ± 0.11	**0.65 ± 0.14**	**0.99 ± 0.05**	**0.87 ± 0.06**	**1.83 ± 0.06**	-0.26 ± 0.15	**0.12 ± 0.04**
Mixed Wood	**-0.56 ± 0.09**	-0.48 ± 0.41	**-0.19 ± 0.07**	**-0.30 ± 0.07**	**-1.19 ± 0.08**	0.05 ± 0.05	**0.47 ± 0.04**
Riparian	0.19 ± 0.11	**0.80 ± 0.15**	**0.71 ± 0.04**	**0.51 ± 0.04**	**0.19 ± 0.07**	**0.62 ± 0.05**	**0.69 ± 0.03**
Water	-	-	**-0.45 ± 0.07**	**-0.50 ± 0.07**	-	-	-0.06 ± 0.05
Lowland Open	**0.77 ± 0.18**	-	**1.60 ± 0.09**	**0.70 ± 0.07**	-0.20 ± 0.16	**-0.27 ± 0.10**	**0.77 ± 0.04**
constant	**-7.41 ± 1.65**	**-6.62 ± 2.06**	**-6.39 ± 0.35**	**-2.30 ± 0.31**	**-5.38 ± 0.54**	**-6.02 ± 0.43**	**-1.34 ± 0.21**

* = averaged model

Table G5. Continued.

Parameter	**157***	**160***	**161***
Elevation (km)	**10.39 ± 0.91**	**14.06 ± 1.60**	**-5.14 ± 2.42**
Elevation $(km)^2$	**-4.01 ± 0.37**	**-4.79 ± 0.58**	1.05 ± 0.98
Eastness	**-0.53 ± 0.02**	-0.01 ± 0.02	**-0.33 ± 0.02**
Northness	**0.23 ± 0.02**	**0.10 ± 0.02**	**0.33 ± 0.02**
Wolf Risk	**-0.11 ± 0.03**	**-0.10 ± 0.02**	**0.08 ± 0.02**
Bear Risk	-	-	-
Conifer	-0.03 ± 0.03	**-0.58 ± 0.03**	**-0.45 ± 0.03**
Alpine	**-1.74 ± 0.13**	**-0.97 ± 0.06**	**-1.04 ± 0.11**
Lowland Shrub	**0.26 ± 0.03**	**0.38 ± 0.03**	**0.36 ± 0.03**
Upland Shrub	**0.61 ± 0.03**	0.02 ± 0.02	**-0.10 ± 0.05**
Mixed Wood	**-0.15 ± 0.04**	-0.01 ± 0.05	-0.02 ± 0.04
Riparian	**1.04 ± 0.04**	**1.17 ± 0.03**	**0.69 ± 0.03**
Water	-	-	-
Lowland Open	-	-	**0.55 ± 0.10**
constant	**-8.58 ± 0.56**	**-11.89 ± 1.10**	**2.89 ± 1.49**